HURRICANES AND CLIMATE

CURRENT CHALLENGES

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Image: NASA.

Goals

- Document changes in hurricane statistics, with as little inhomogeneity as possible and quantified uncertainty. As far back as possible.
- Represent the (two-way?) interactions between hurricanes and climate in dynamical models
- Predict/project changes and variations in hurricane statistics
- Extend our window of predictability
- Expand the suite of predictable characteristics beyond basin-wide quantities
- Attribute changes in hurricane statistics to particular factors, in a scientifically rigorous manner

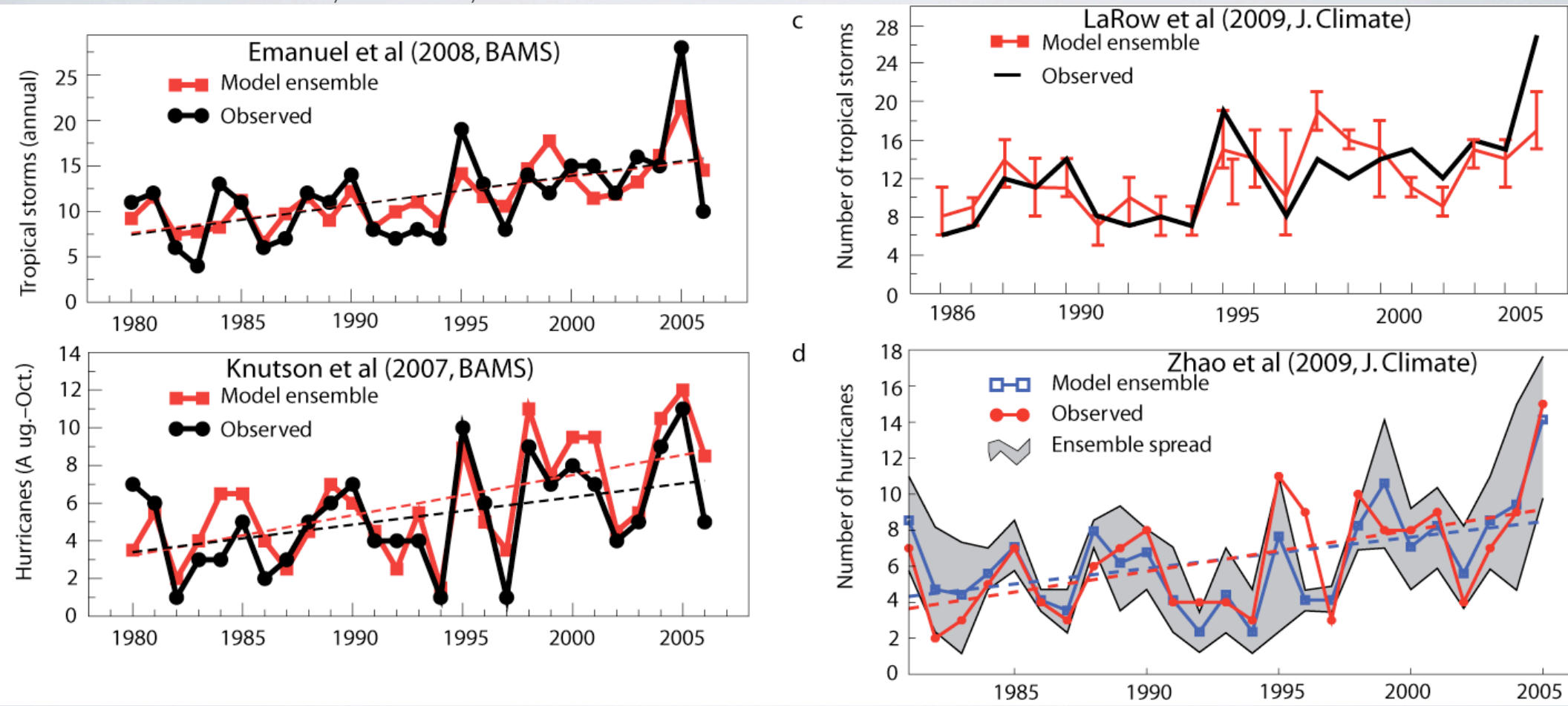
Outline

- Climate modeling of hurricanes
- Hurricanes and ocean climate
- Seasonal hurricane forecasts
- Observational issues
- Hurricane theory
- Summary of key issues

Dynamical Models Exhibit Skill in Seasonal Basin-wide Hurricane Frequency

Statistical-dynamical hybrid model

100km SST-forced AGCM



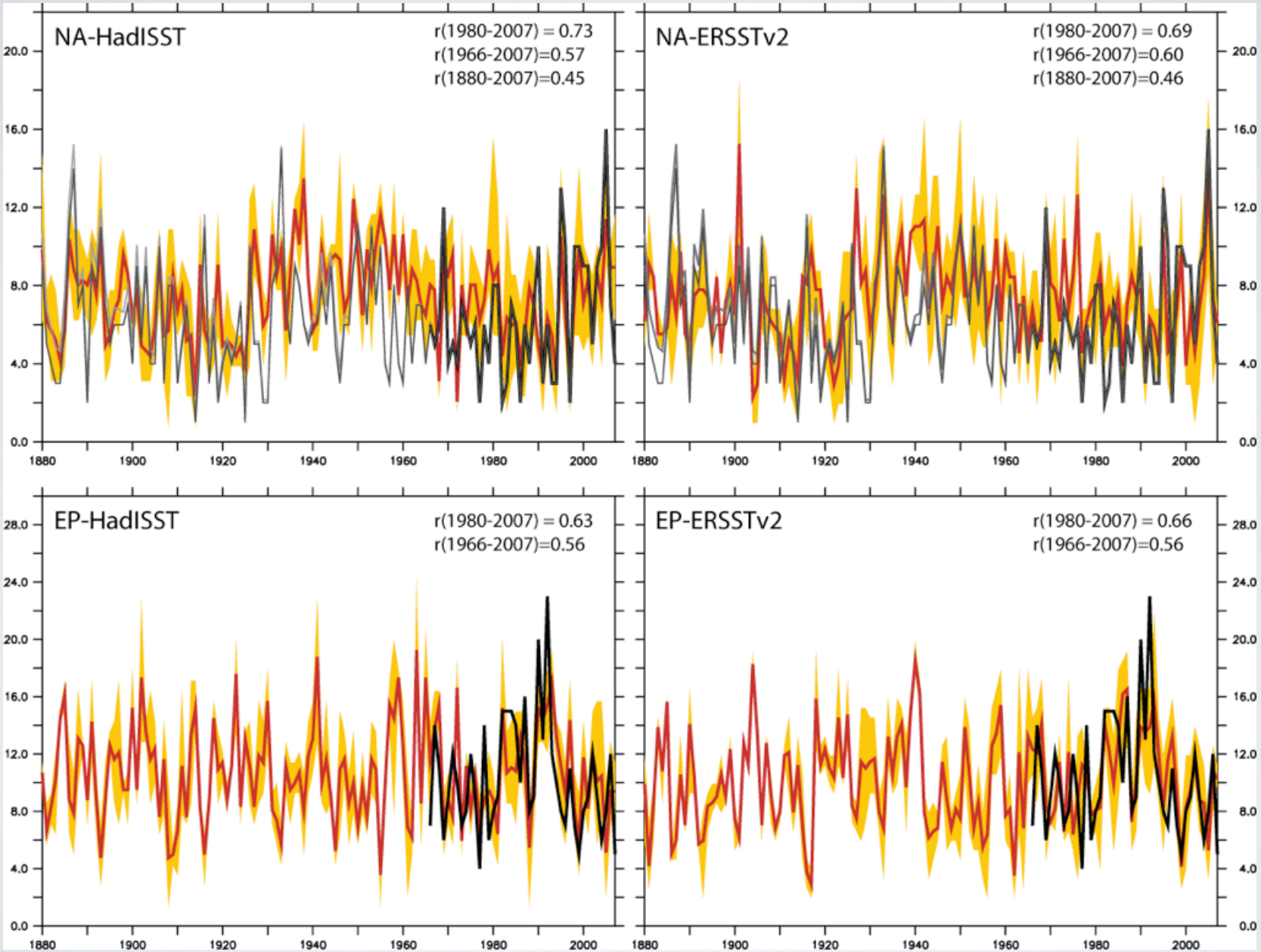
18-km regional model

50km SST-forced AGCM

Figure adapted from Knutson et al (2010, Nat. Geosci.)

CENTURY-SCALE SST-FORCED AGCM HINDCASTS

Using 100km version of Zhao et al (2009, J. Clim.) AGCM

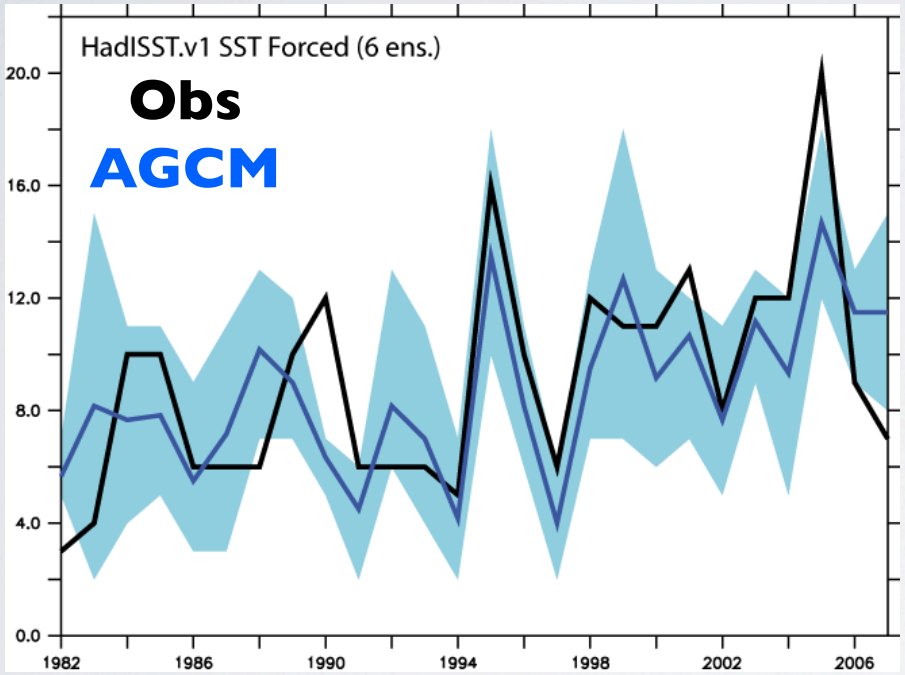


Vecchi et al (2010, in prep.)

Model Response Exhibits Sensitivity To Forcing Used

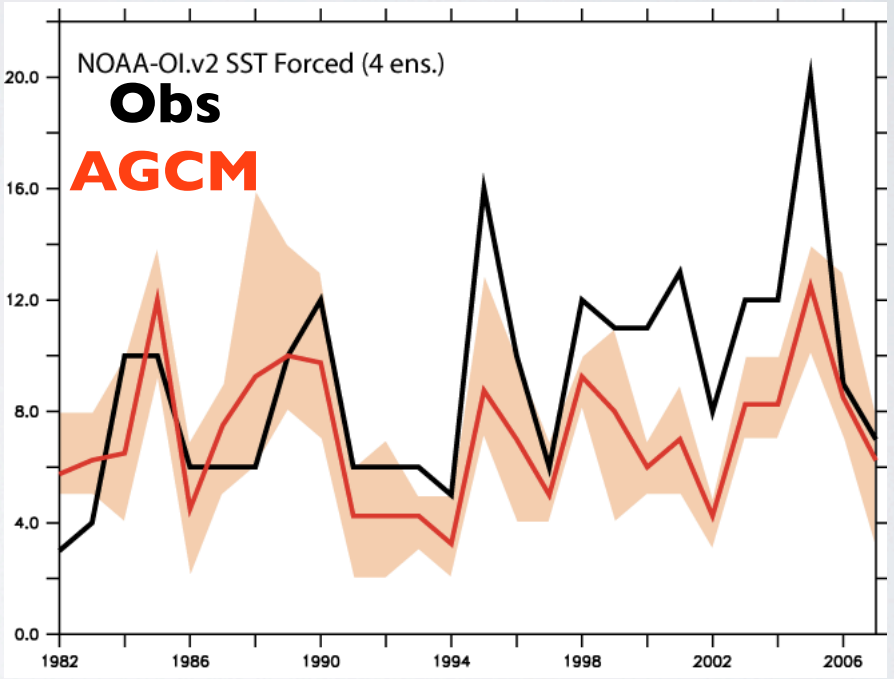
Tropical Storm Frequency Response to Same
AGCM but different estimates of observed SST

HadISST forced



AGCM is 100km version of Zhao et al (2009, J. Clim.)

NOAA-OI.v2 forced

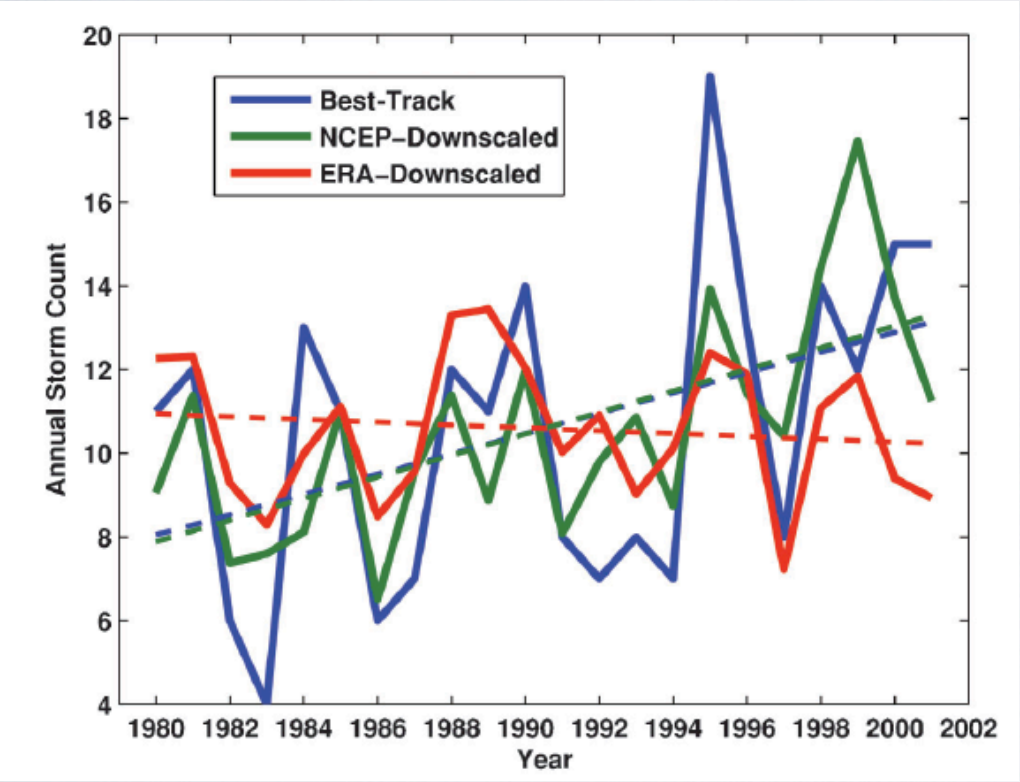


Vecchi et al (2010, in prep.)

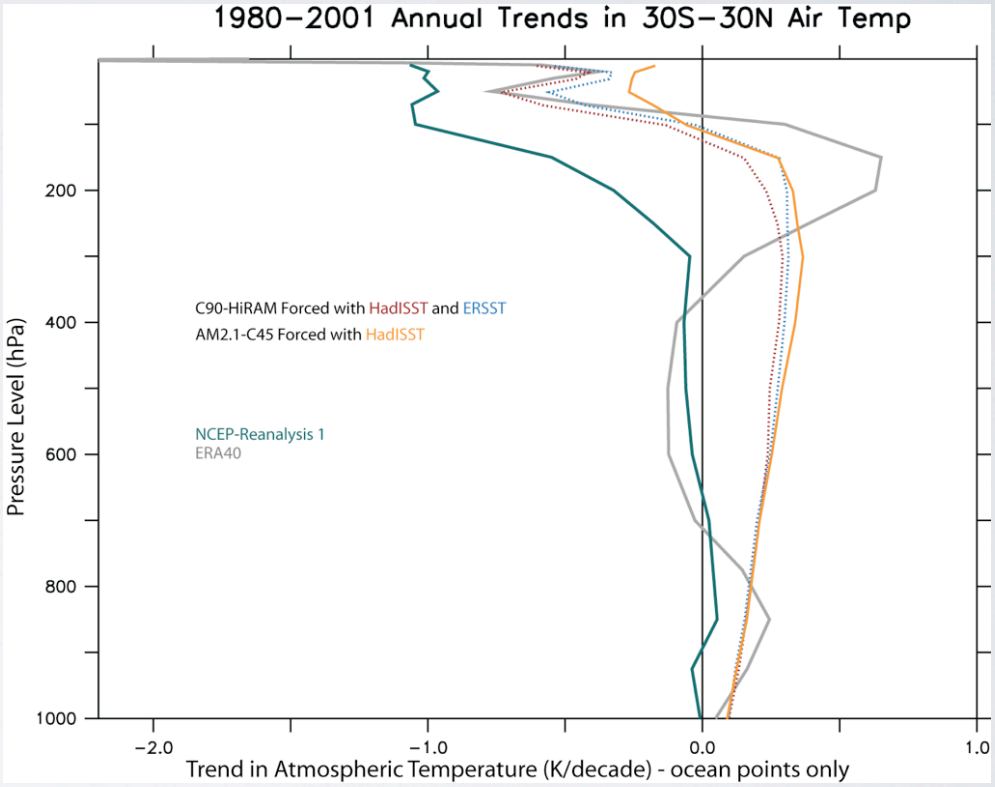
How do we evaluate model skill in this context?

Model Response Exhibits Sensitivity To Forcing Used

Response of Model Depends on Reanalysis Used



Tropical-mean temperature change in upper troposphere and tropopause layer is the key difference



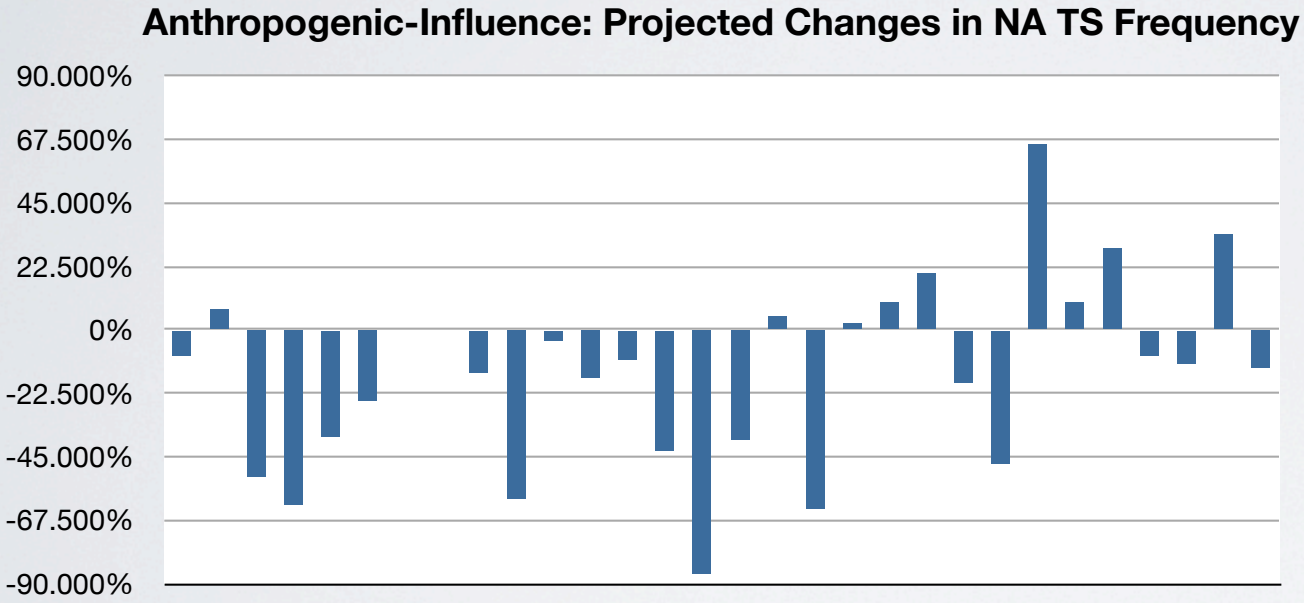
Emanuel (2010, JAMES); strong sensitivity also found in Knutson et al (2007) regional model framework

How do we evaluate model skill in this context?
Opens door for direct radiative forcing to affect TCs

Divergence of 21st Century projections of TS Frequency

- Even sign of NA TS frequency response to GHG unclear: Not big help in decadal predictability

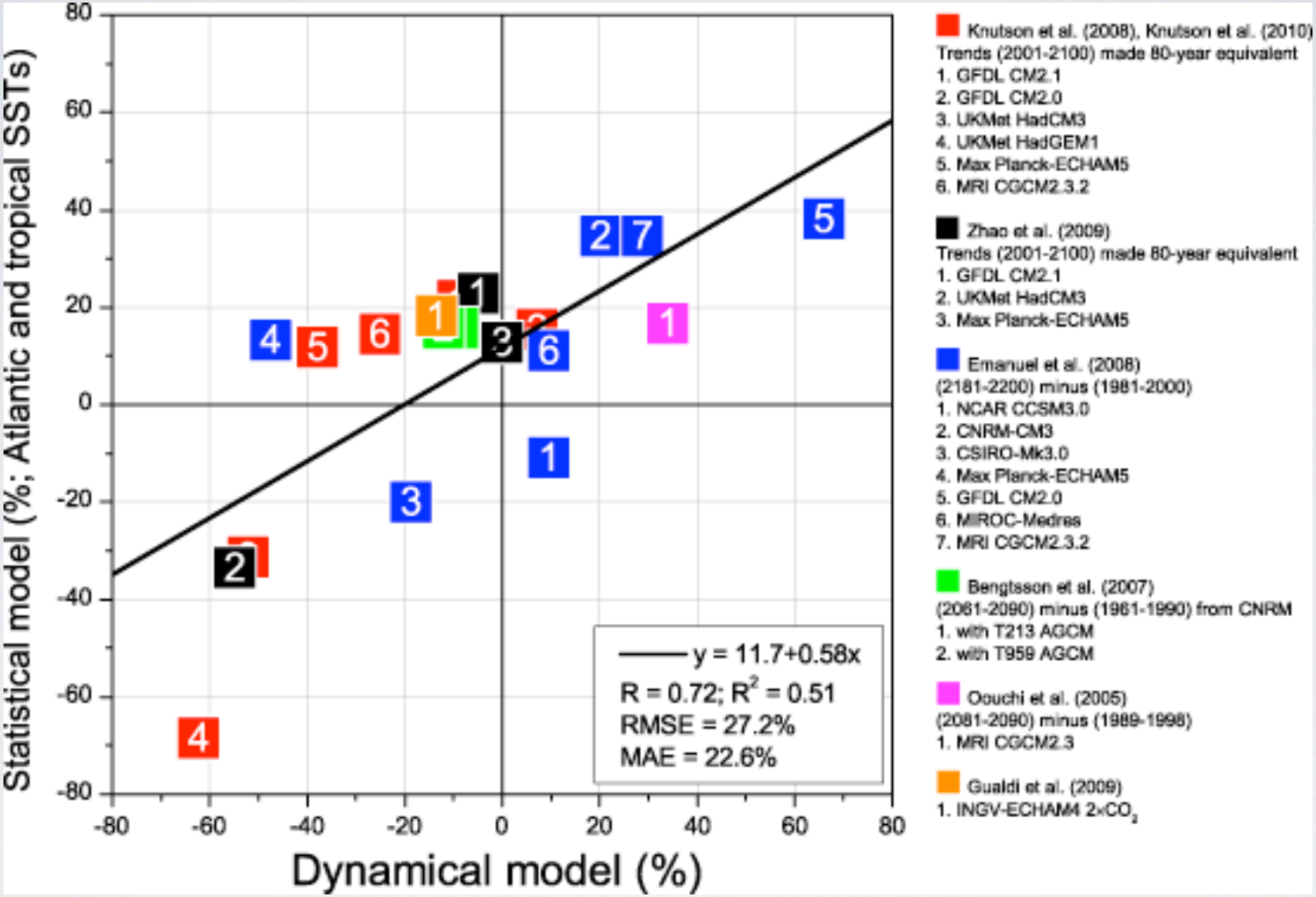
- Various studies downscale different coupled models, and over different periods



Oouchi et al (2005), Bengtsson et al (2007), Emanuel et al (2008), Knutson et al (2008), Zhao et al (2008)

Is there any consistency in the various projections?

DYNAMICAL MODELS EXHIBIT CONSISTENT RELATIONSHIP TO MDR AND TROPICAL SSTS - ALL CONSISTENT WITH OBSERVATIONS

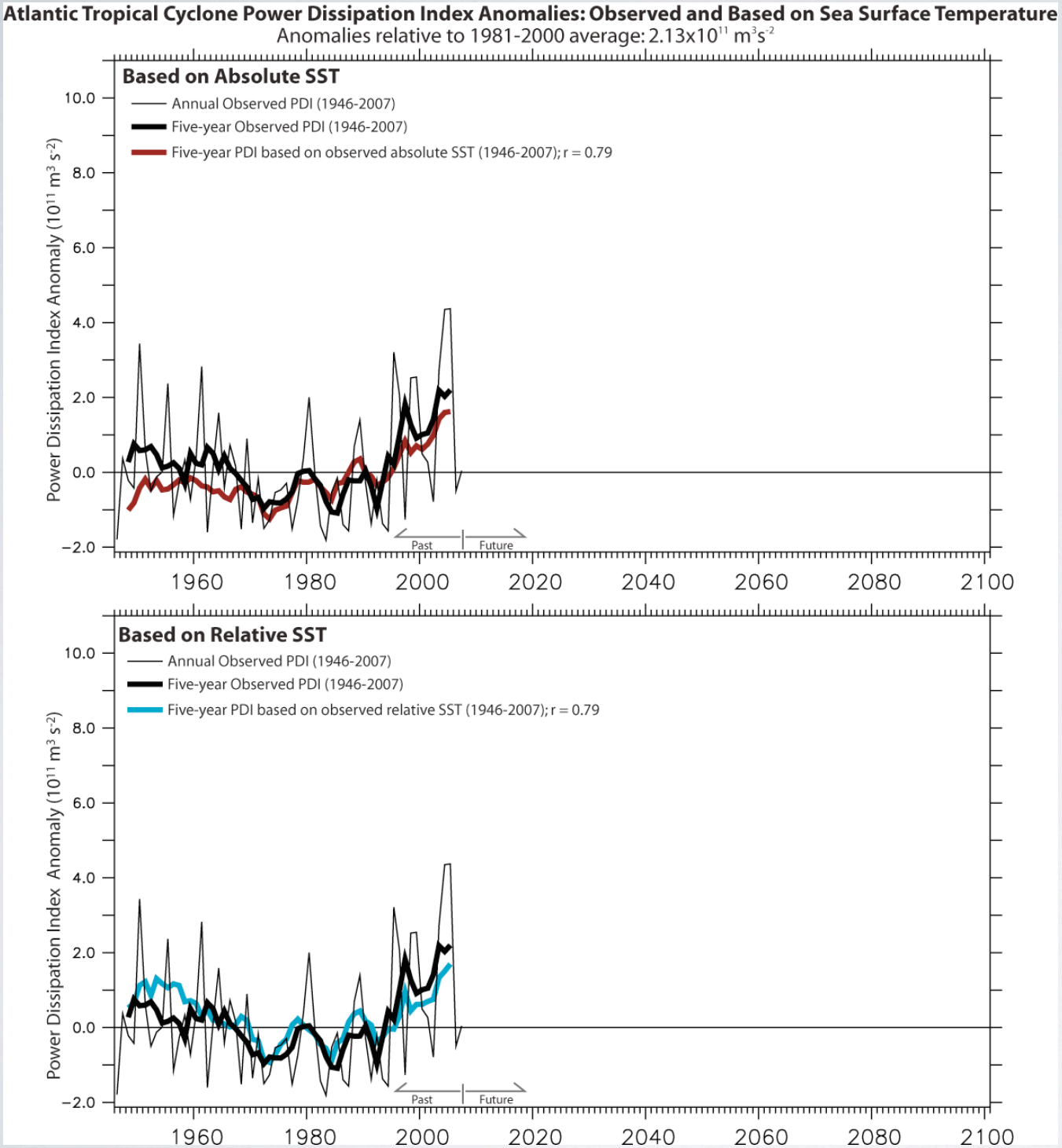


Villarini et al (2010, J. Clim. submitted)

Poisson model of 2-day duration TS (vertical) vs. dynamical downscaling results (horizontal)

Statistical Models/Downscaling Tools

- Many predictors are being used:
  - are they equivalent? in which contexts?
  - which are most predictable?
- How best to assess the applicability of a statistical model?
  - what is the relevant out of sample test?
  - we have limited observational records
  - many predictors covary over historical period



Observed Activity

Absolute MDR SST

see also Emanuel (2005, 2007)

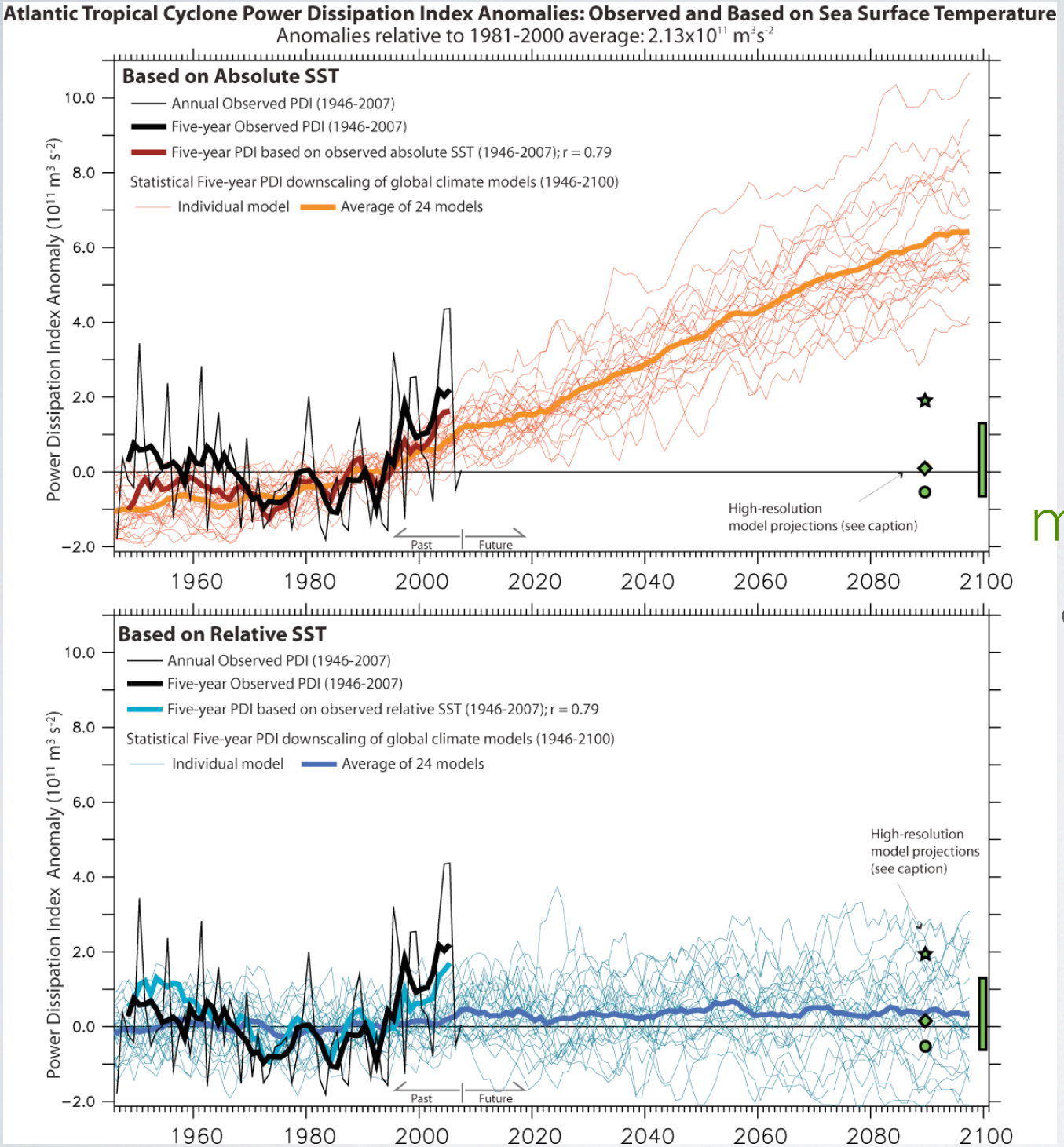
If causal, can attribute to GHG.

Relative MDR SST

If causal, cannot attribute.

see also Swanson (2008)

Vecchi, Swanson and Soden (2008, Science)



Observed Activity

Absolute SST

Model Abs. SST

High-resolution model activity change

Emanuel et al (08),Knutson et al (08)
Oouchi et al (06),Bengtsson et al (07)

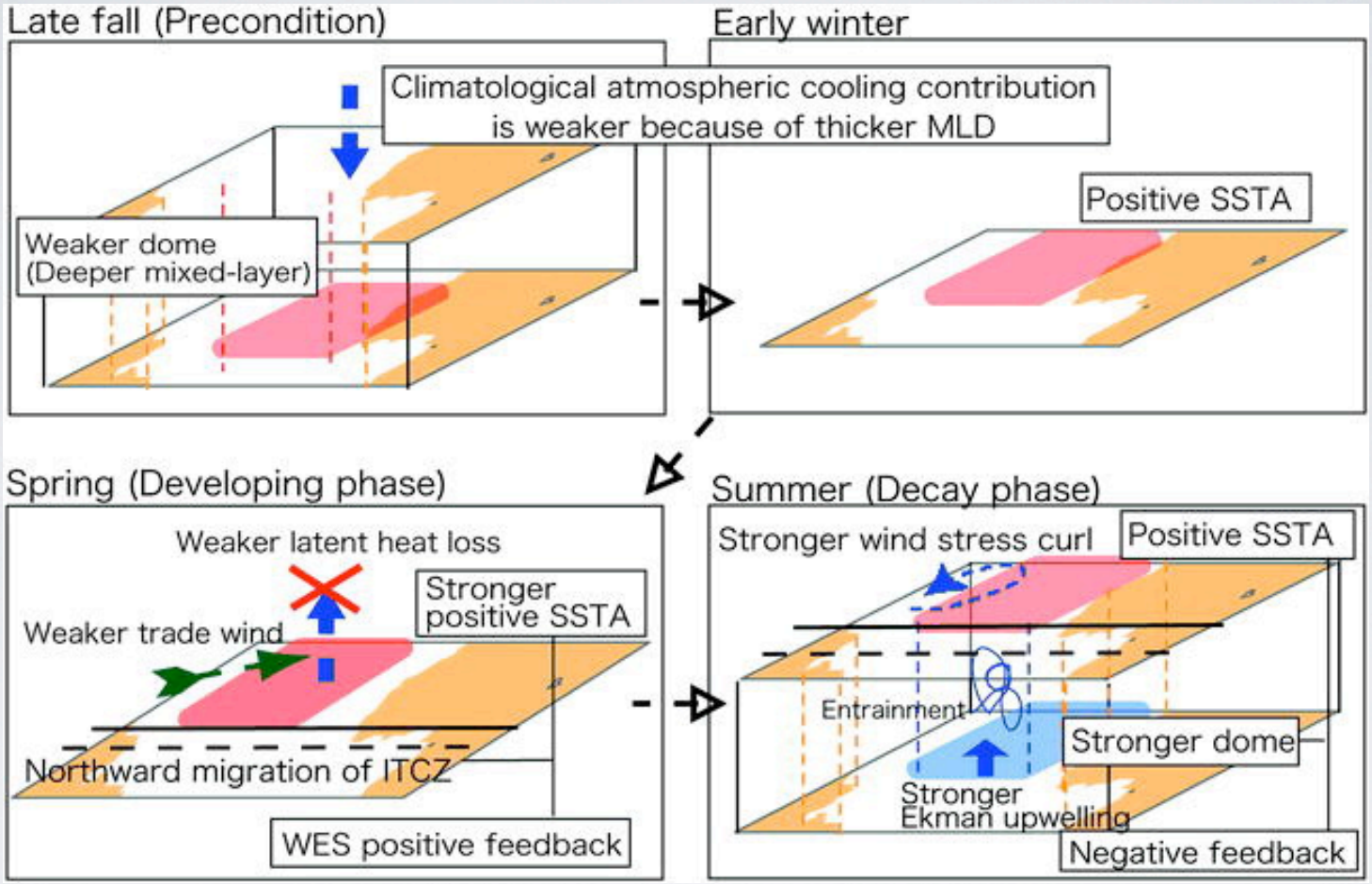
Relative SST

Model Rel. SST

Vecchi, Swanson and Soden (2008, Science)

Ocean climate and hurricanes

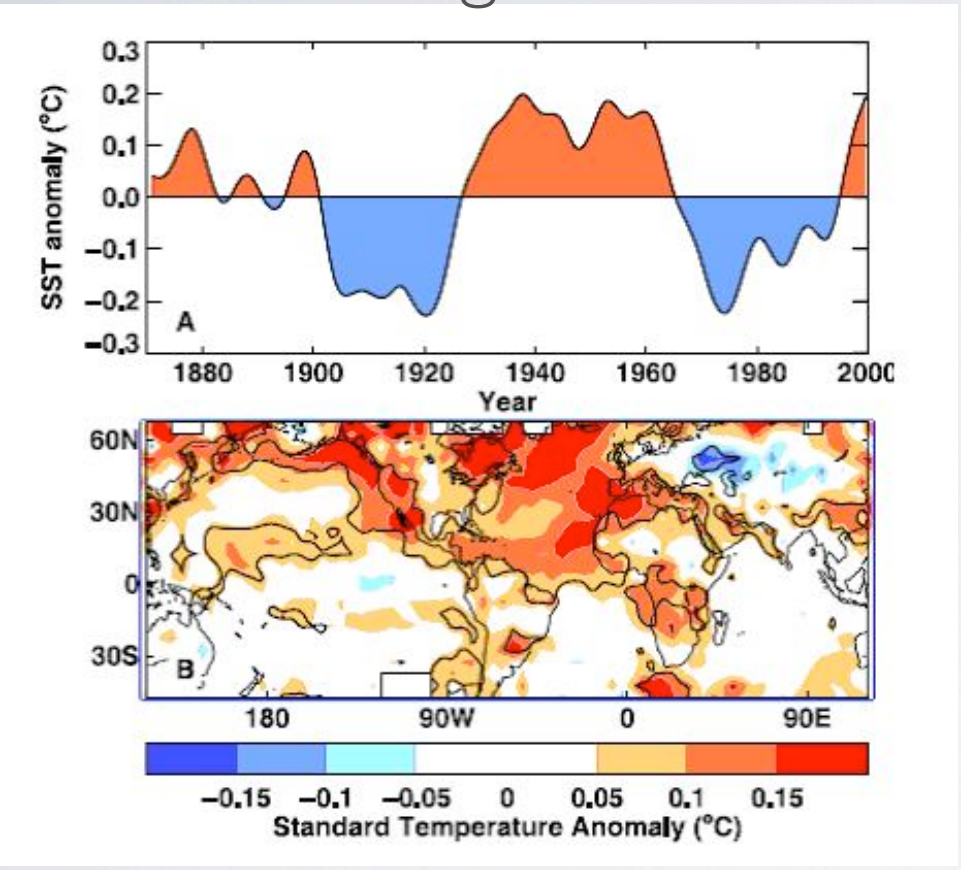
Processes Controlling Interannual Tropical Atlantic Variability are Seasonally Dependent



Doi et al. (2010, J. Climate)

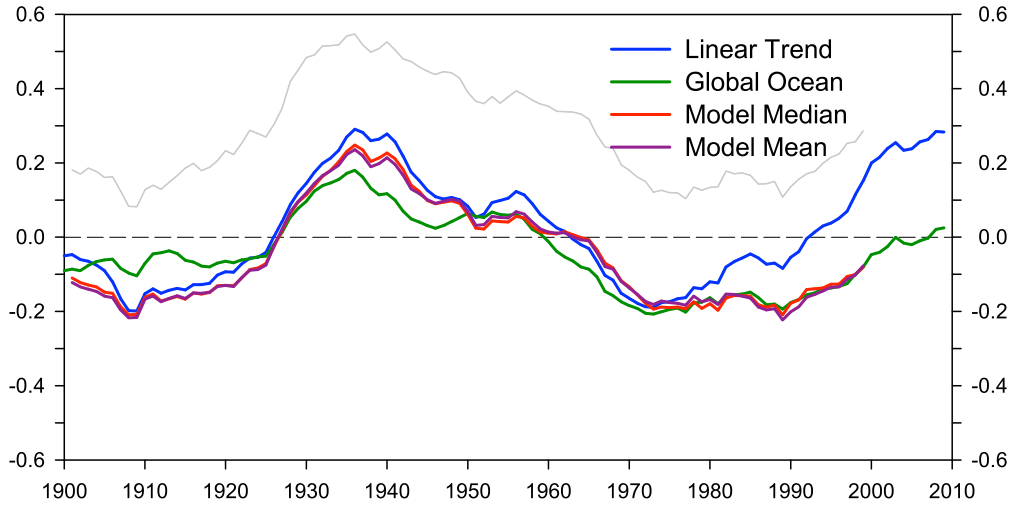
Biases in tropical Atlantic mean state and seasonal variability can influence character of interannual changes.

AMO and regression to TS



Knight et al (2005, Nature)

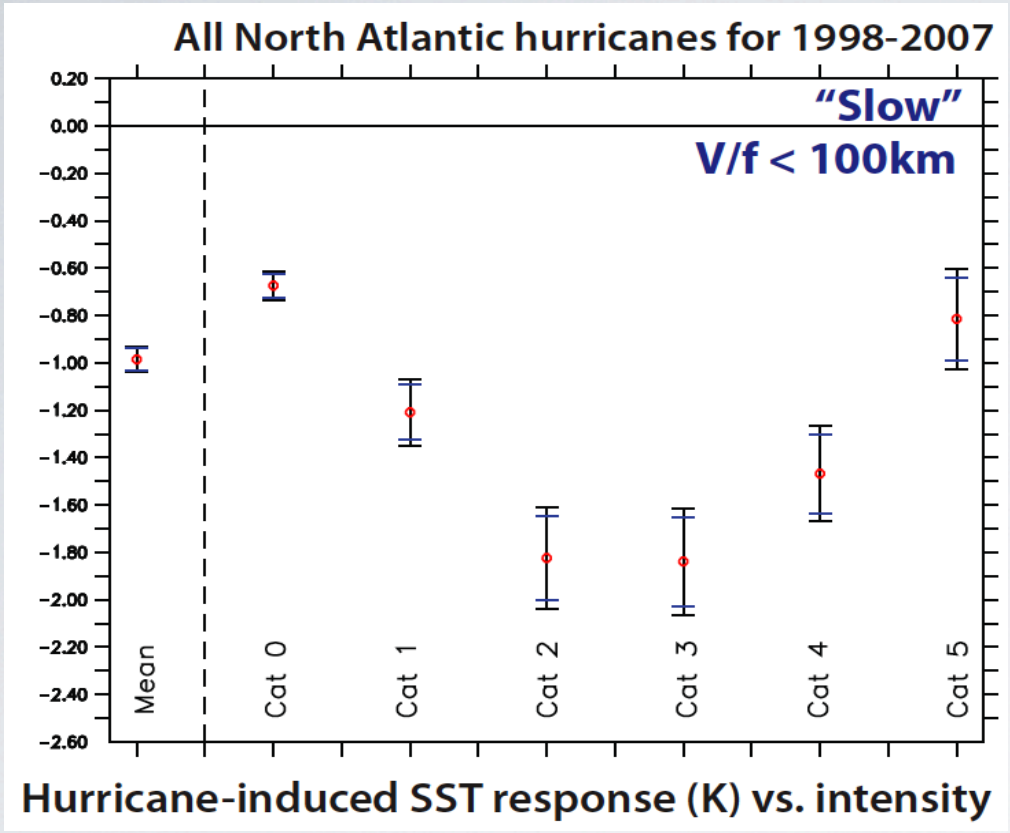
Alternative definitions of AMO

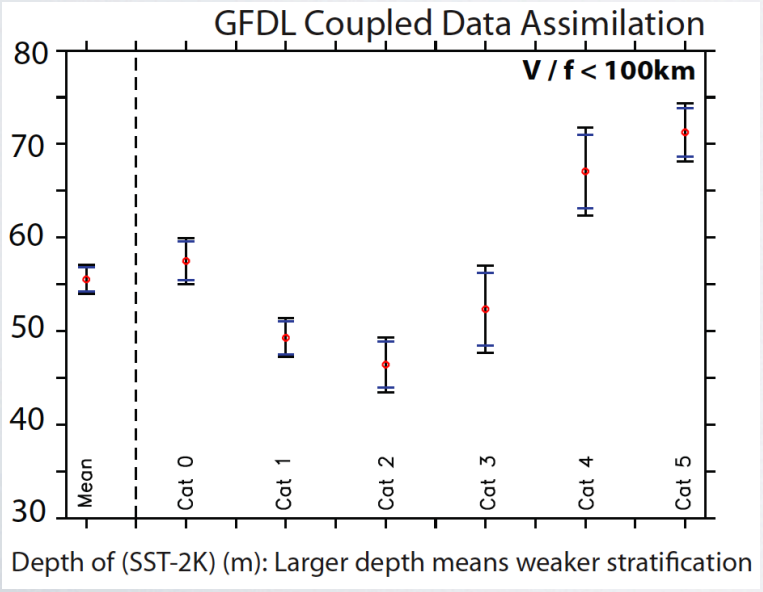


1) Observed NAO SSTA - Observed Linear Trend
2) Observed NAO SSTA - Observed Global Ocean (60N-60S) SSTA
3) Observed NAO SSTA - Median Value of IPCC AR4 20C3M NAO SSTA
4) Observed NAO SSTA - Mean Value of IPCC AR4 20C3M NAO SSTA

Figure by Eui-Seok Chung

OBSERVATIONAL EVIDENCE FOR OCEANIC CONTROLS ON HURRICANE INTENSITY





Lloyd and Vecchi
(2010, J. Clim. submitted)

Few temperature obs.
at depth in GOM

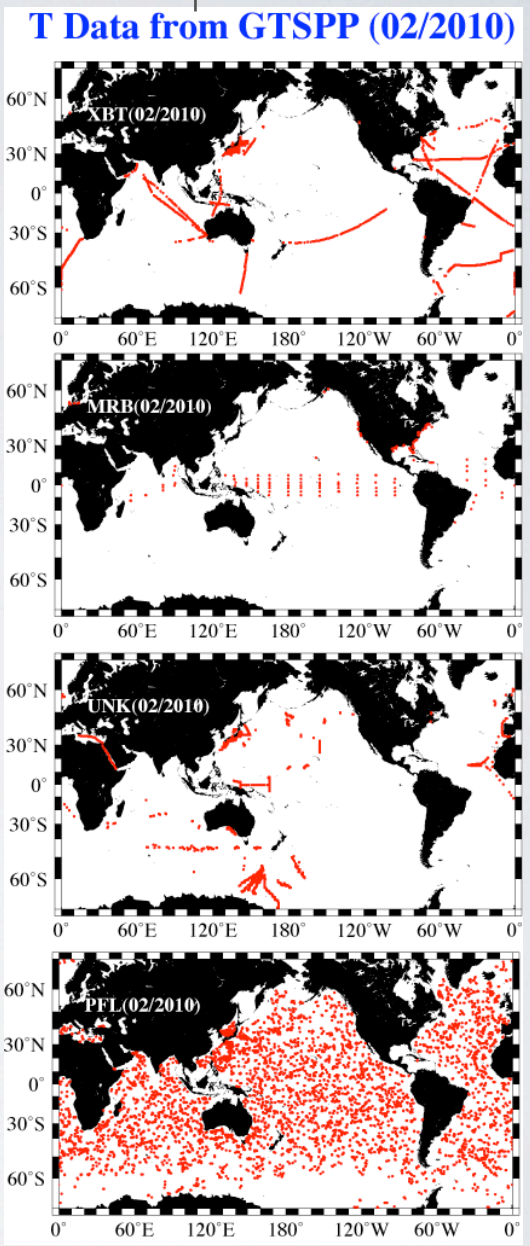
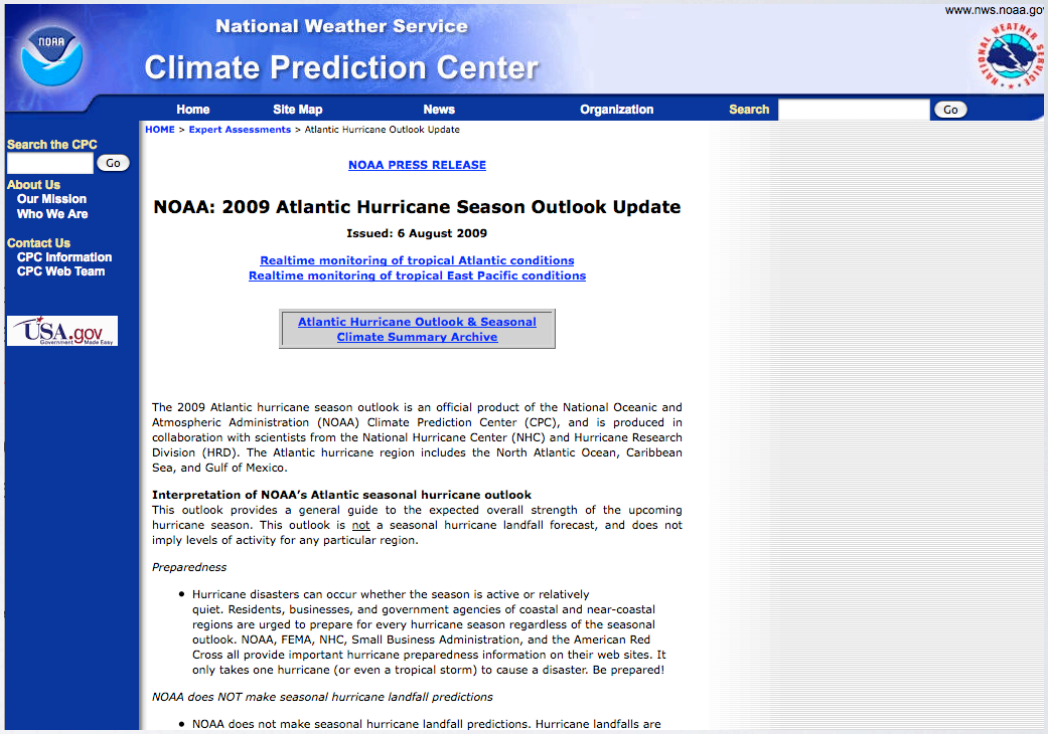


Figure Shaoqing Zhang

FORECASTS

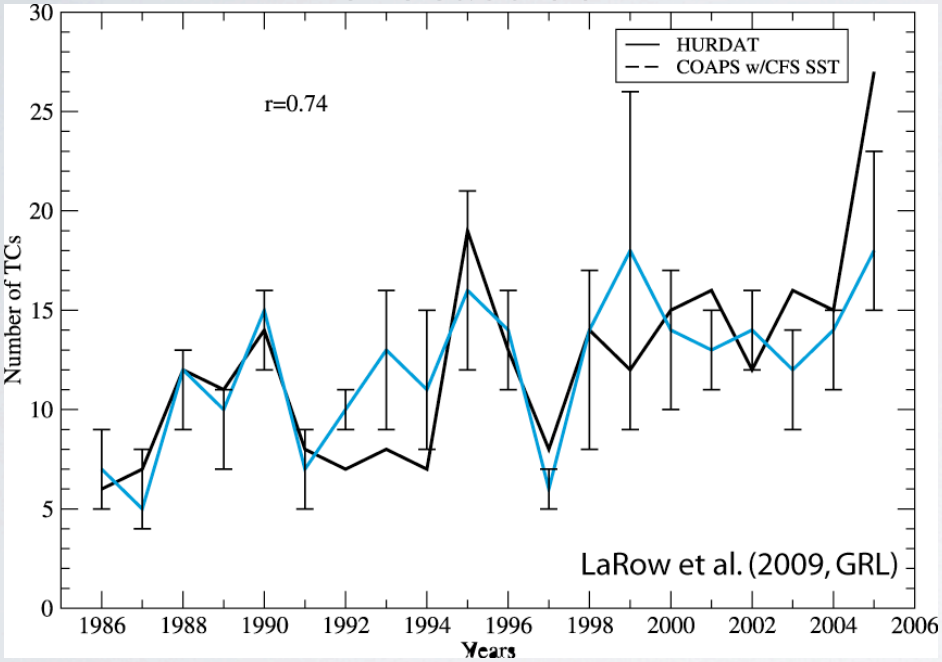
Seasonal Hurricane Forecasts Initialized in Boreal mid-Spring to early-Summer Are: Feasible, Potentially Skillful and Made

- Statistical prediction schemes (e.g., Gray, Klotzbach and Gray, Elsner et al)
- Dynamical prediction schemes (e.g., Vitart , Vitart et al, LaRow et al)
- Hybrid schemes (e.g., Wang et al, Zhao et al, Vecchi et al)

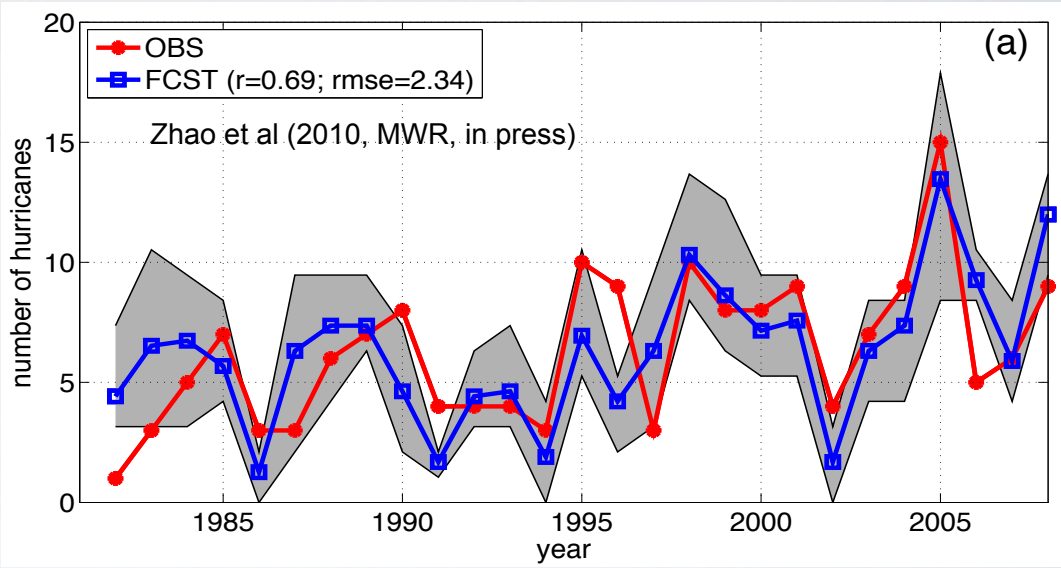


Two-tiered Dynamical Forecast Schemes with AGCMs Exhibit Skill

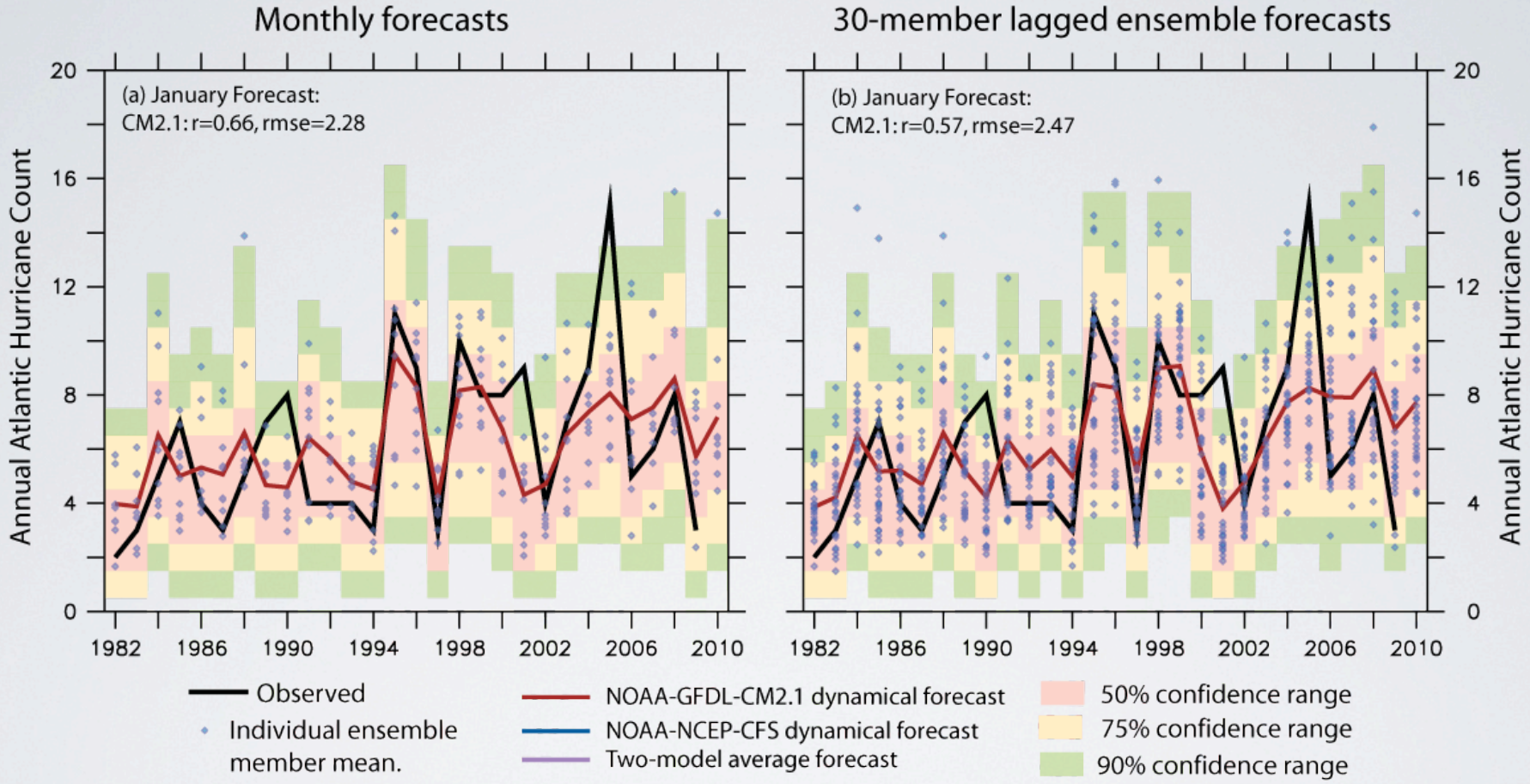
AGCM driven by CFS June 1 Forecast SST



AGCM driven by Persisted June SSTA



Statistical-Dynamical Hurricane Frequency Retrospective Forecasts Initialized January Exhibit Skill

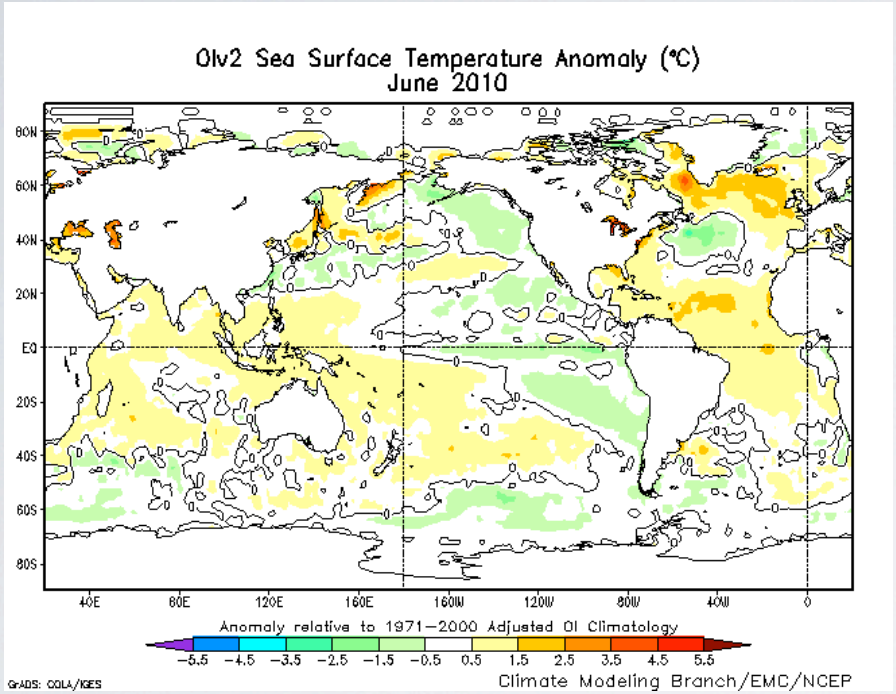


$$p(C=k) = \int_{-\infty}^{\infty} p(C=k \mid \text{relSSTA}=x) \cdot p(\text{relSSTA} = x)\, dx$$

p(relSSTA=x) from CM2.1 ensemble

Vecchi *et al.* (2010, MWR submitted)

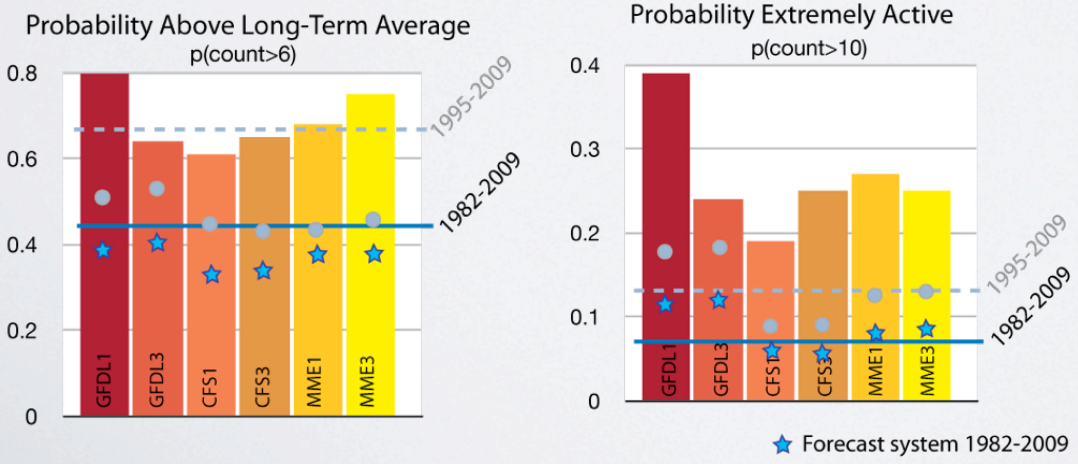
Current SST Anomaly Field is Consistent with 2010 Becoming An Extremely Active Year (basin-wide)



NOAA's May 2010 outlook:
85% above average
10% average
5% below average
NOAA Outlook not for landfall

TSR, CSU forecasts also active

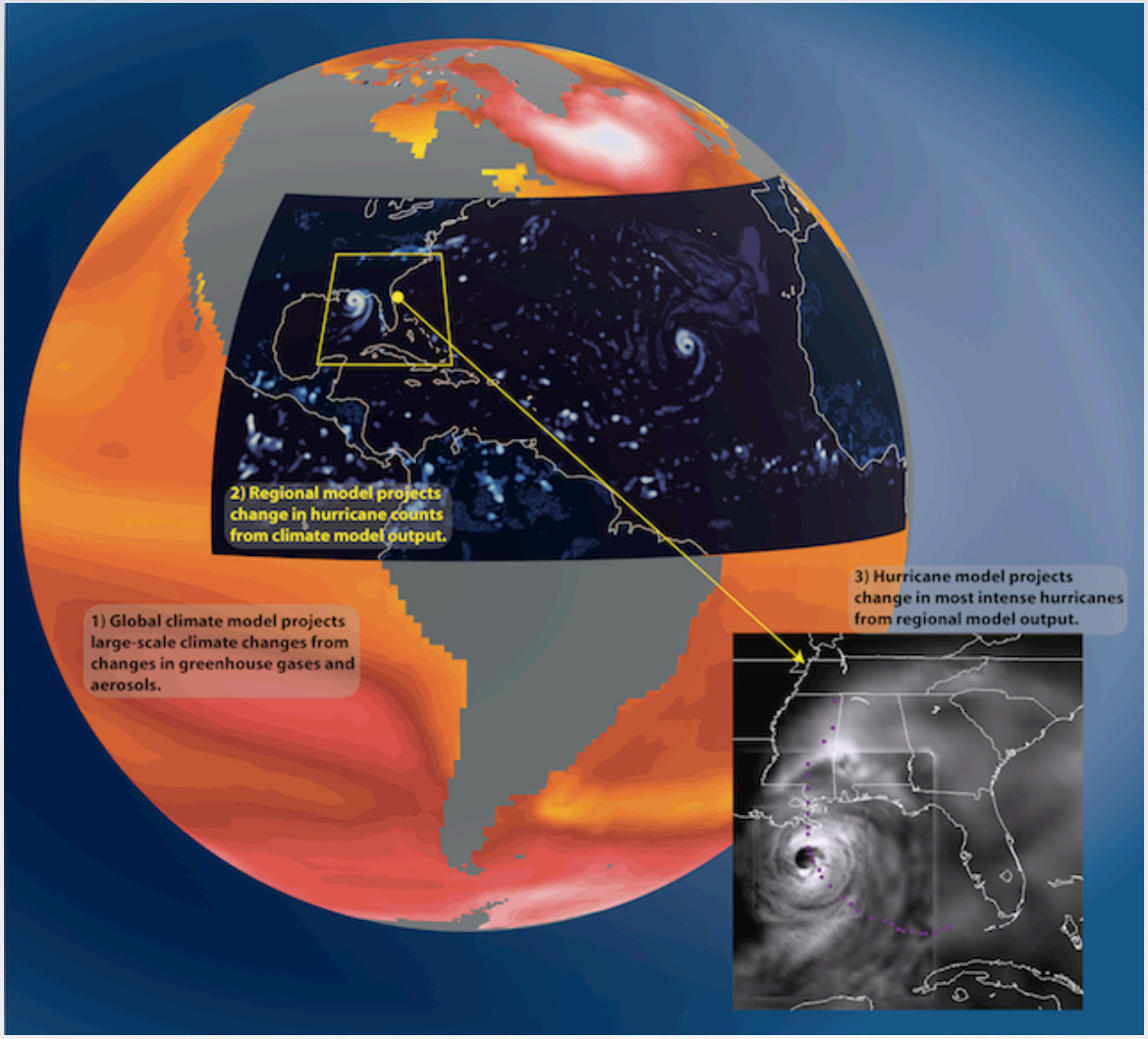
Atlantic SSTA substantially warmer than the tropical mean
This type of conditions foreseen by initialized GCMs since late-2009.



March 2010
initialized forecasts.

Vecchi et al. (2010, MWR)

Multi-Step Downscaling to Get Extreme Hurricanes?

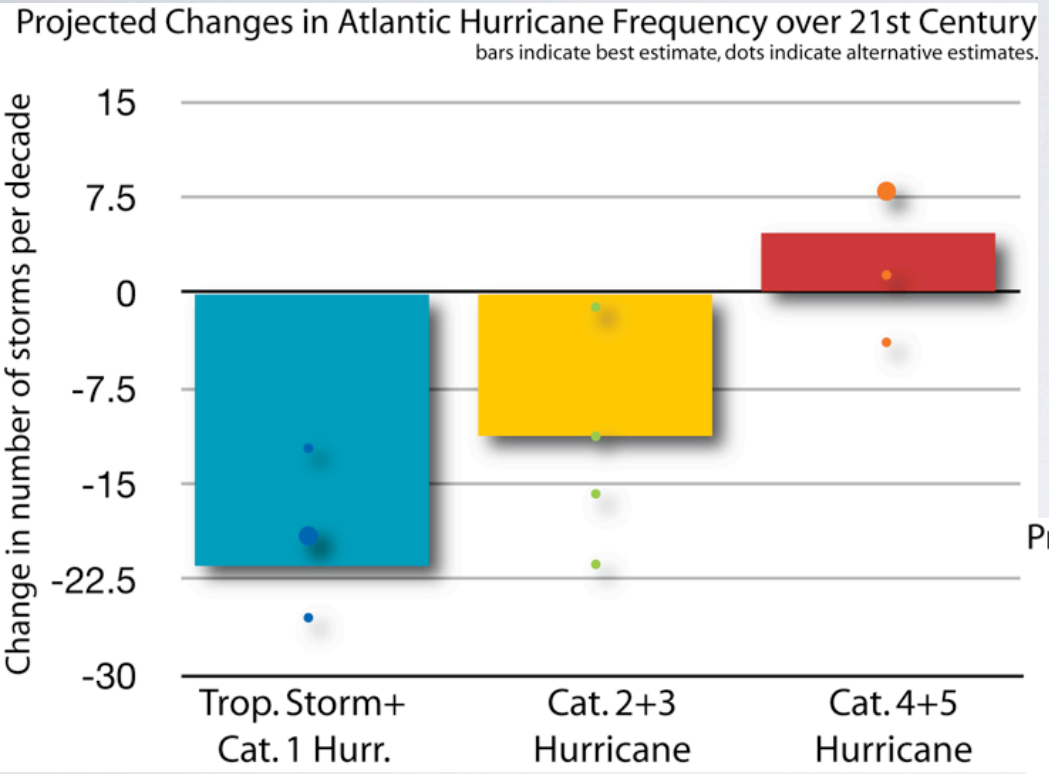


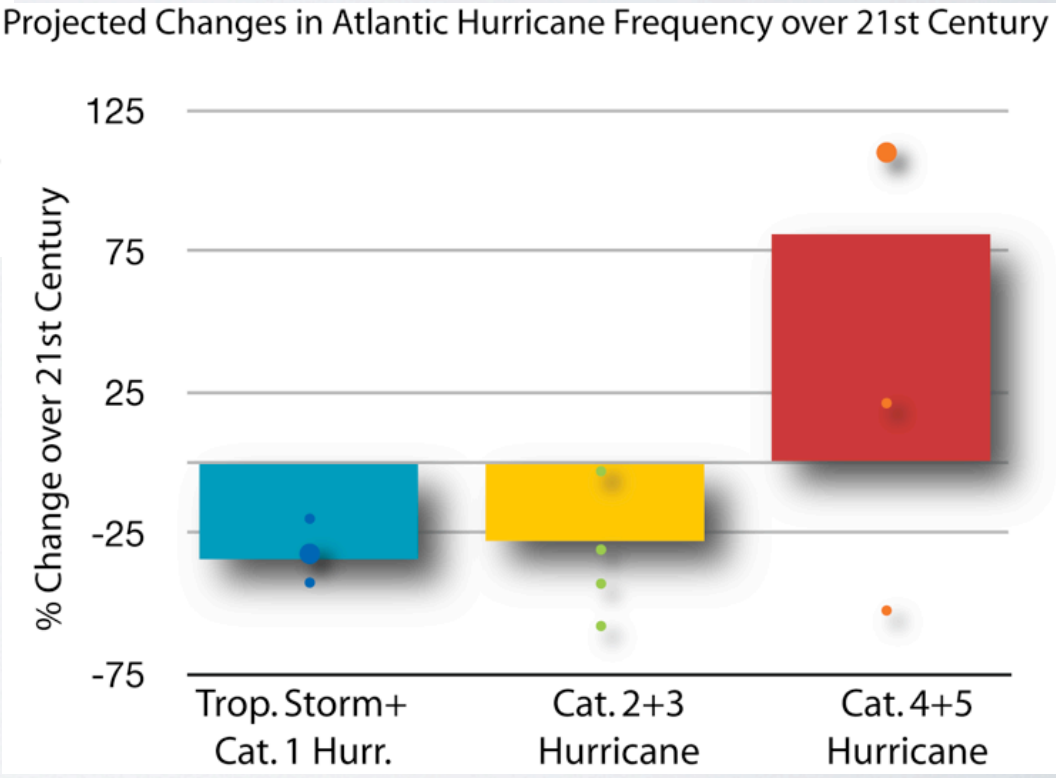
Adapted from
Bender et al (2010, Science)

Global Climate Models -> Regional Model -> Hurricane model

Large-scale TS Frequency Intensity

Projected Frequency Decreases, Extremes Increase

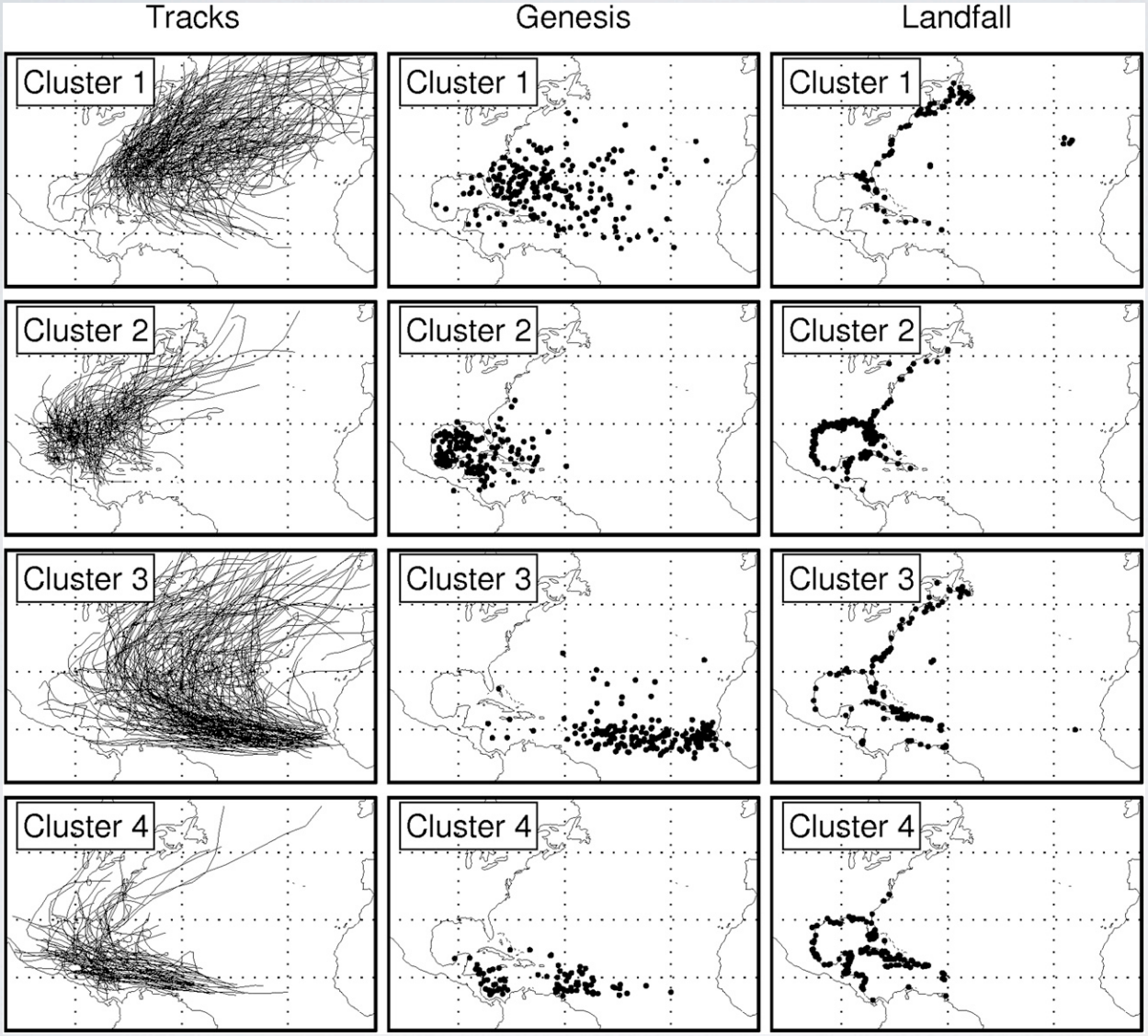




Adapted from Bender et al (2010, Science)

CAN WE EXTEND SEASONAL PREDICTIONS TO LANDFALL?

Observed landfall, track and genesis linked

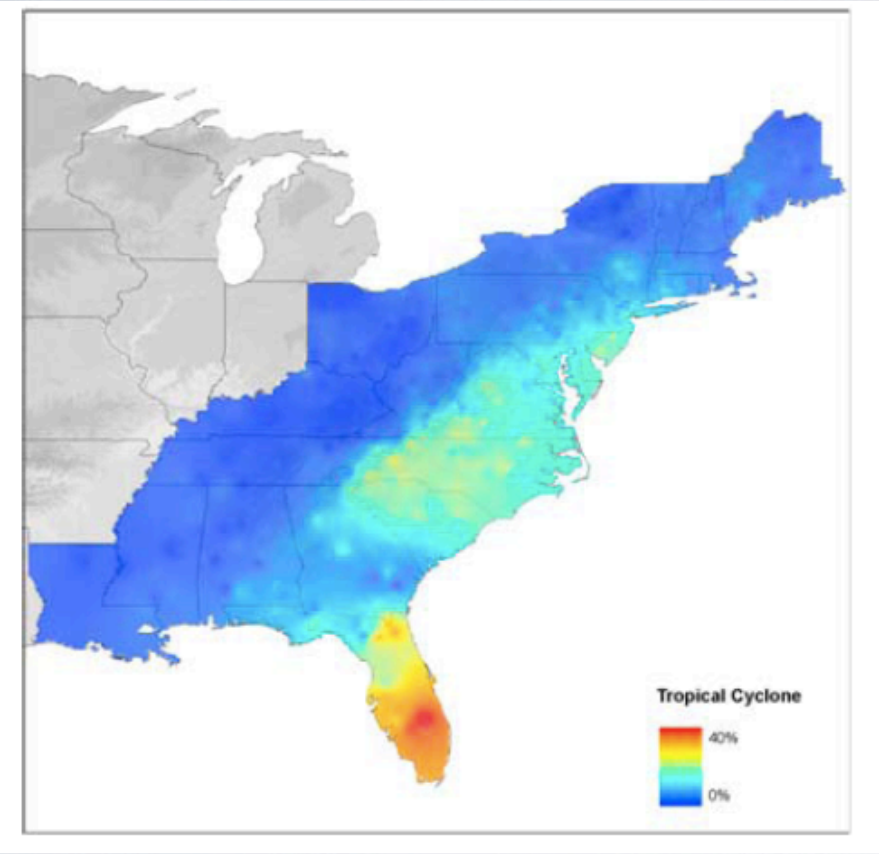


Kossin et al (2010, J. Climate)

Can this type of information be exploited in the climate and forecasting context?

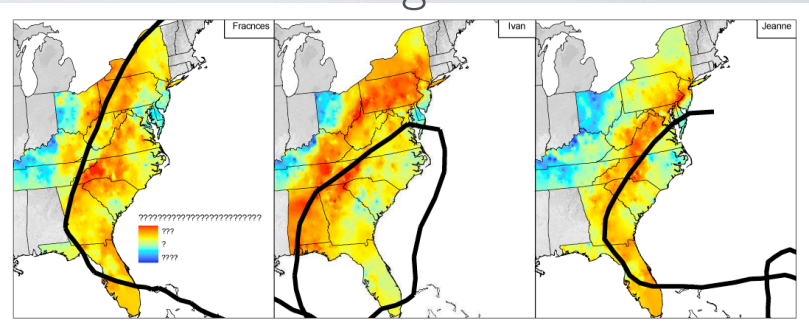
Can we Extend Seasonal Predictions to Landfall?

Fraction of peak river discharge associated with tropical cyclones

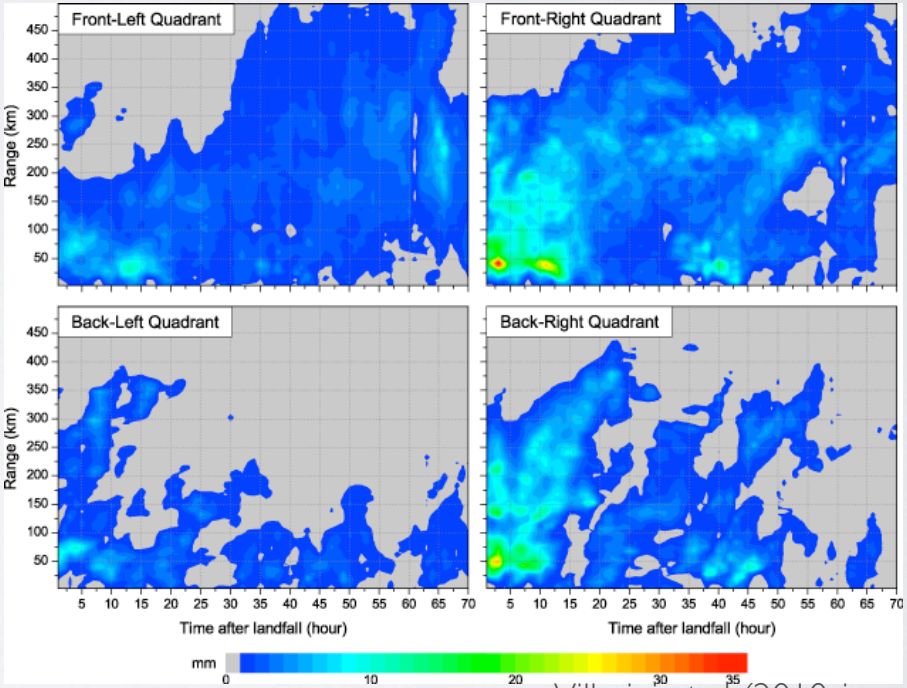


Villarini and Smith (2010, Water Resource Res.)

Three landfalling TCs from 2004



Composite rainfall after landfall

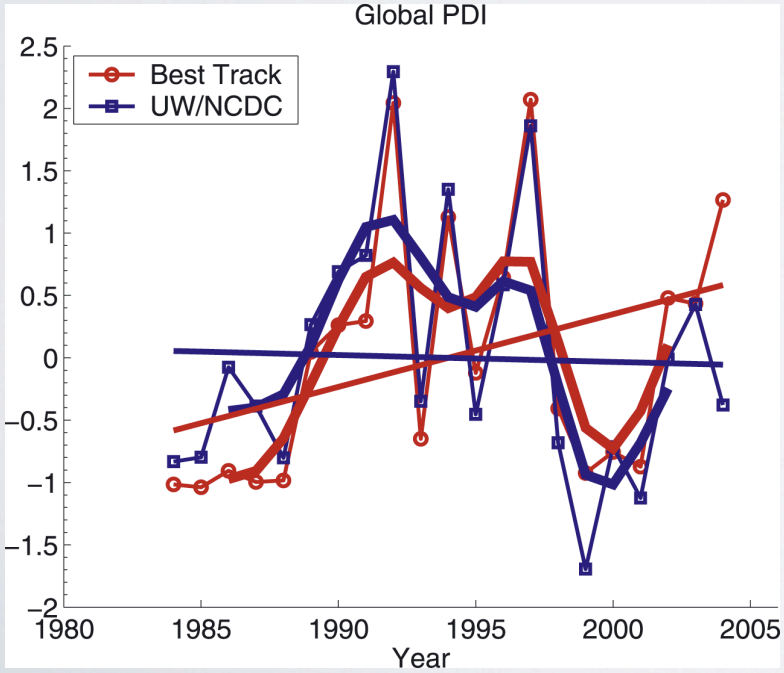


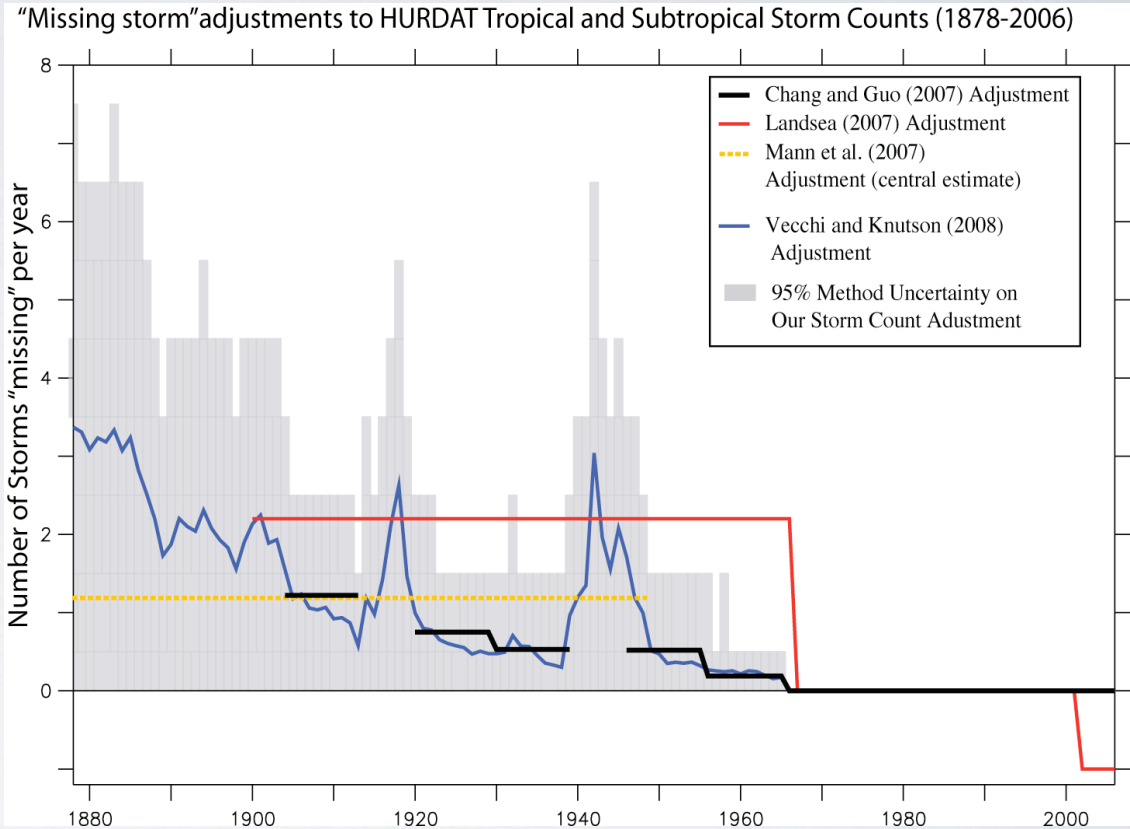
Villarini et al (2010, in prep.)

Can this type of information be exploited in the climate and forecasting context?

OBSERVATIONS

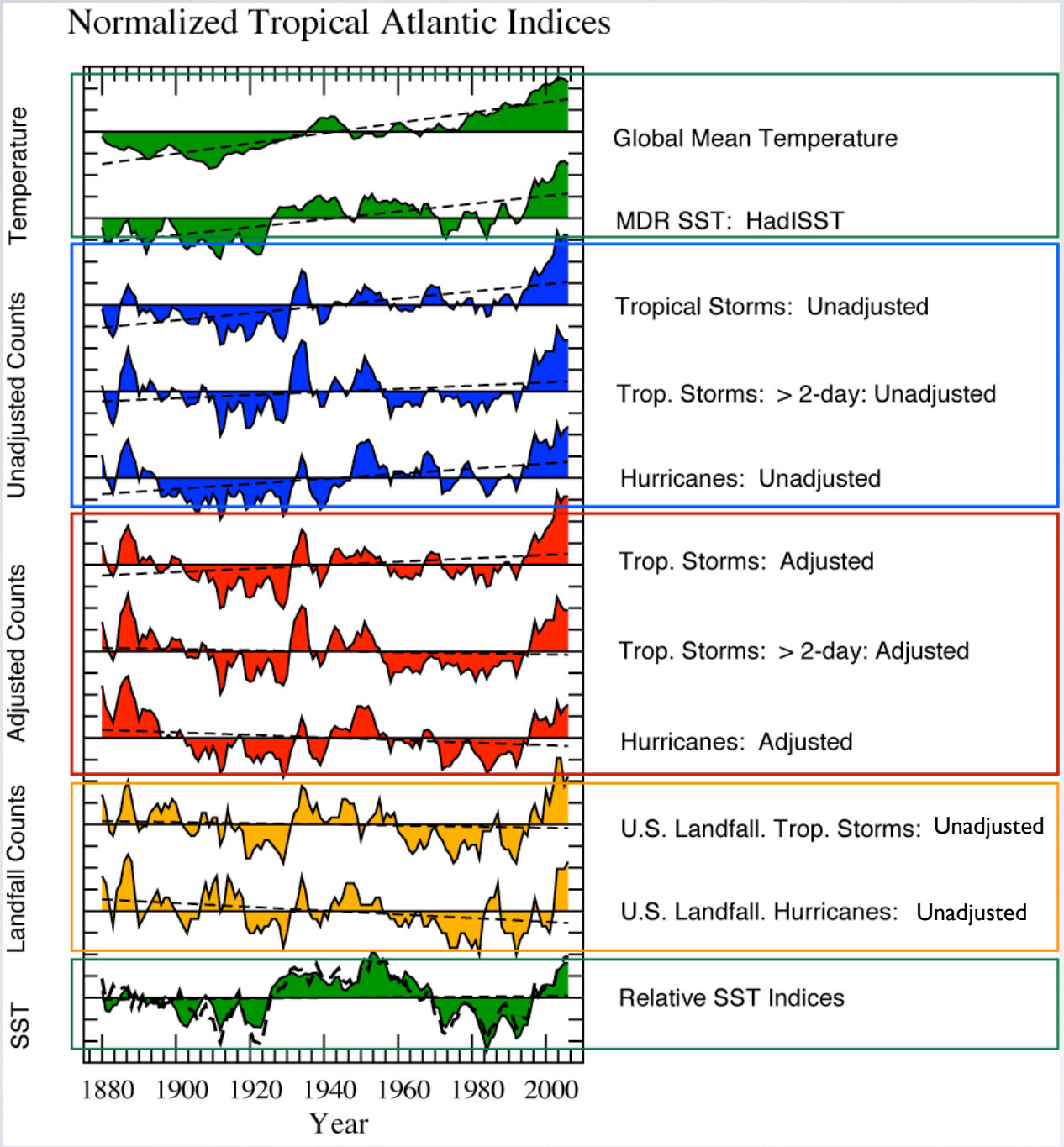
- Hurricane databases not built as climate data records.
- Efforts must continue to:
  - Identify issues
  - Homogenize when possible
  - Estimate uncertainty





Vecchi and Knutson(2008, J. Clim.)

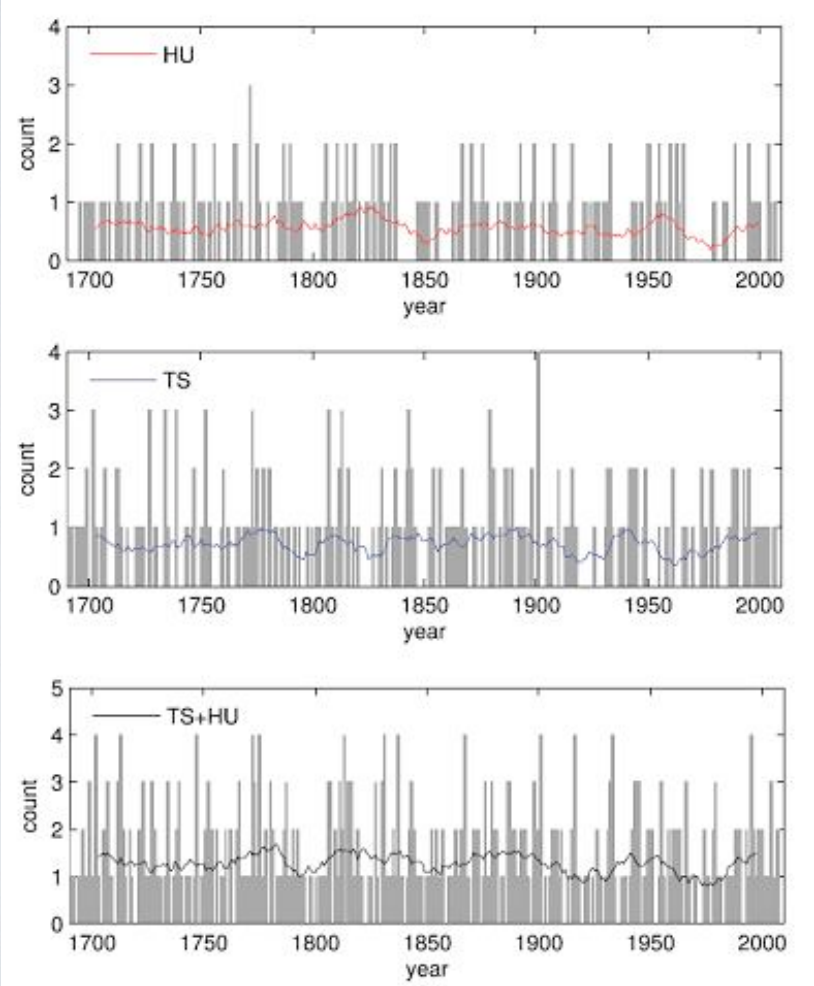
Kossin et al (2007, GRL)



Sources:
Vecchi and Knutson (2008, J. Clim.)
Landsea et al. (2010, J. Clim.)
Vecchi and Knutson (2010, J. Clim. submitted)

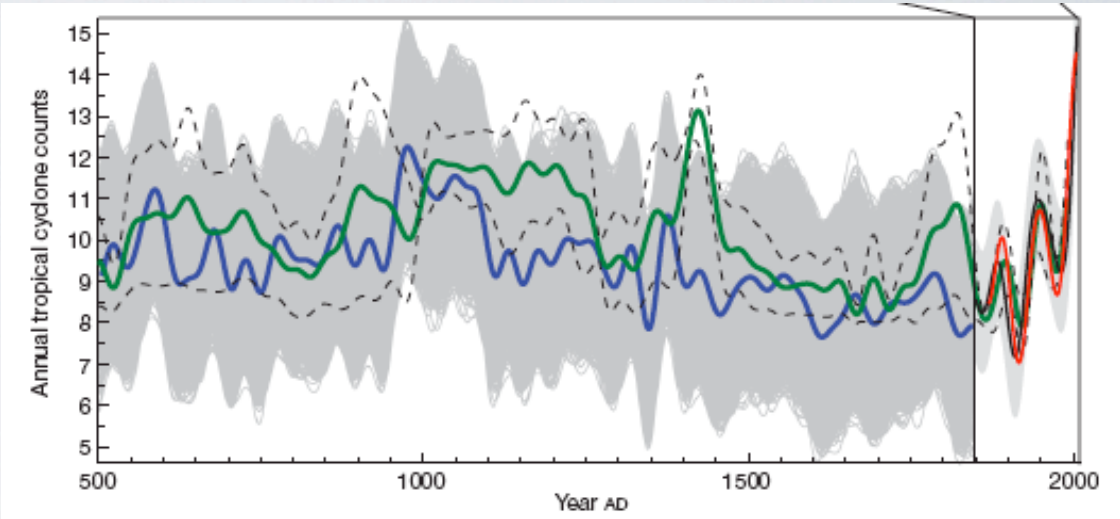
Data Archeology and Paleo-proxy Indicators Complement Instrumental Records

Document-based reconstruction of Antilles TS and HU



Chenoweth and Divine (2008, G3)

Proxy reconstructions of basin-wide TS frequency



Mann et al. (2009, Nature)

Statistical extrapolation, so depends on:

-Validity of statistical model (e.g., predictors chosen)

-Quality of training data

-Quality of proxy data

Theory/Understanding: what controls hurricanes?

- Potential Intensity theory exists (e.g., Emanuel, Holland…)
  - What are limitations? What is relevance to actual intensity change?
- Can we develop a climate-relevant theory for genesis?
  - Idealized and coordinated forcing experiments with AGCMs
  - Development of Genesis Indices

BISTER AND EMANUEL (1998) POTENTIAL INTENSITY

$$PI^2 = V_{red}^2 \frac{c_k}{c_d} \frac{T_s - T_o}{T_o} \left(k_s^* - k_a \right) \Big|_{r_{\max}}$$

- Defined locally from a sounding and SST.
- All other things equal: SST increase-> PI increase

  Both through direct impact on T_s and k*, as well as indirectly impacting T_o and k_a

- However, remote SST changes impact upper tropospheric temperature (e.g., Sobel et al 2002) changing T_o directly and indirectly, and enthalpy diff. indirectly: remote warming acts to reduce PI.

  See also Shen *et al* (2000), Tang and Neelin (2004) and Ramsay and Sobel (2010, submitted)

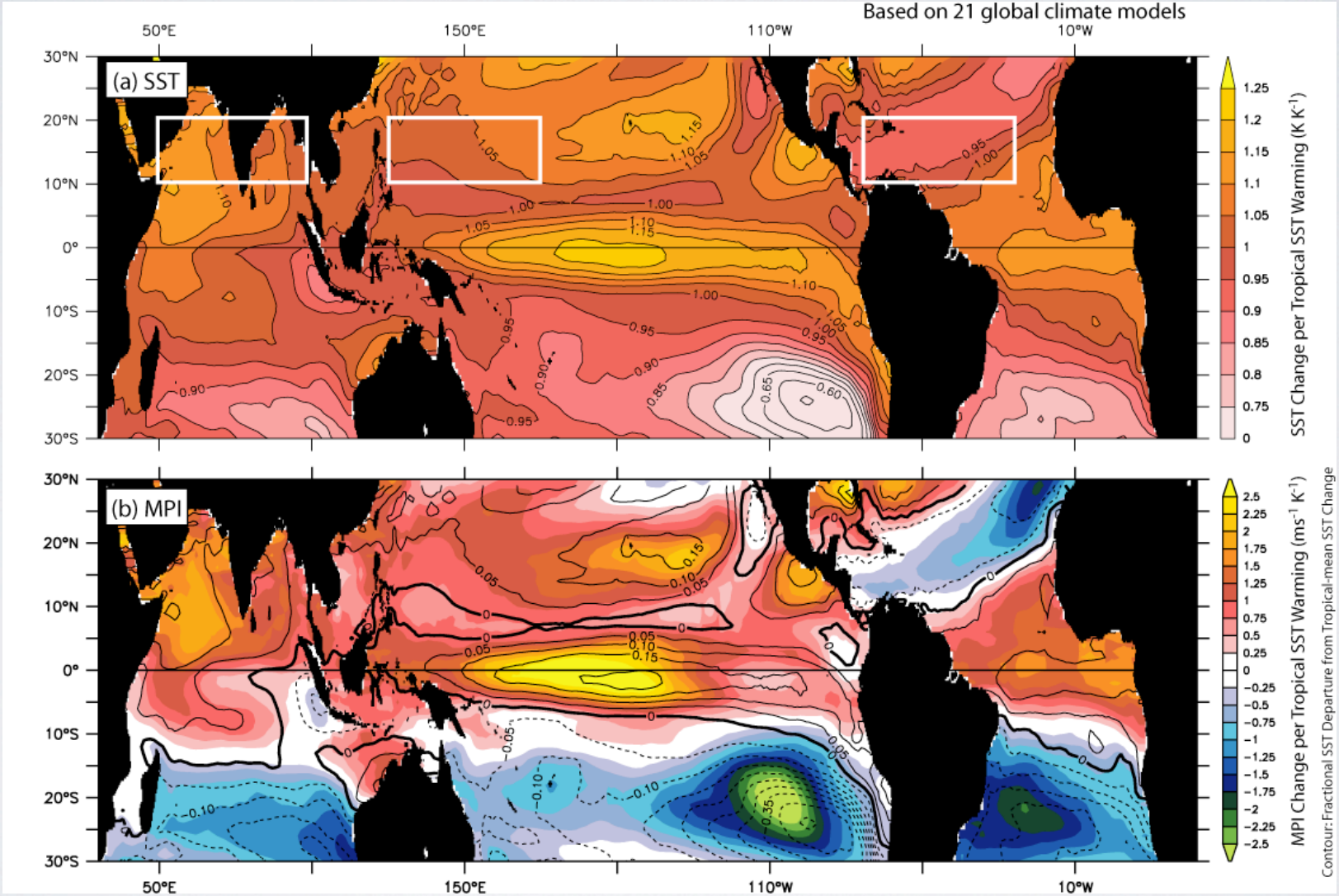
From GCMs, PI'-<PI'> ~ 8 ·(SST'-<SST'>)

In GCMs, |<PI'>| smaller than |PI'|, so PI' ~ 8 ·(SST'-<SST'>)

POTENTIAL INTENSITY TRACKS SST RELATIVE TO TROPICAL-MEAN, NOT LOCAL SST*

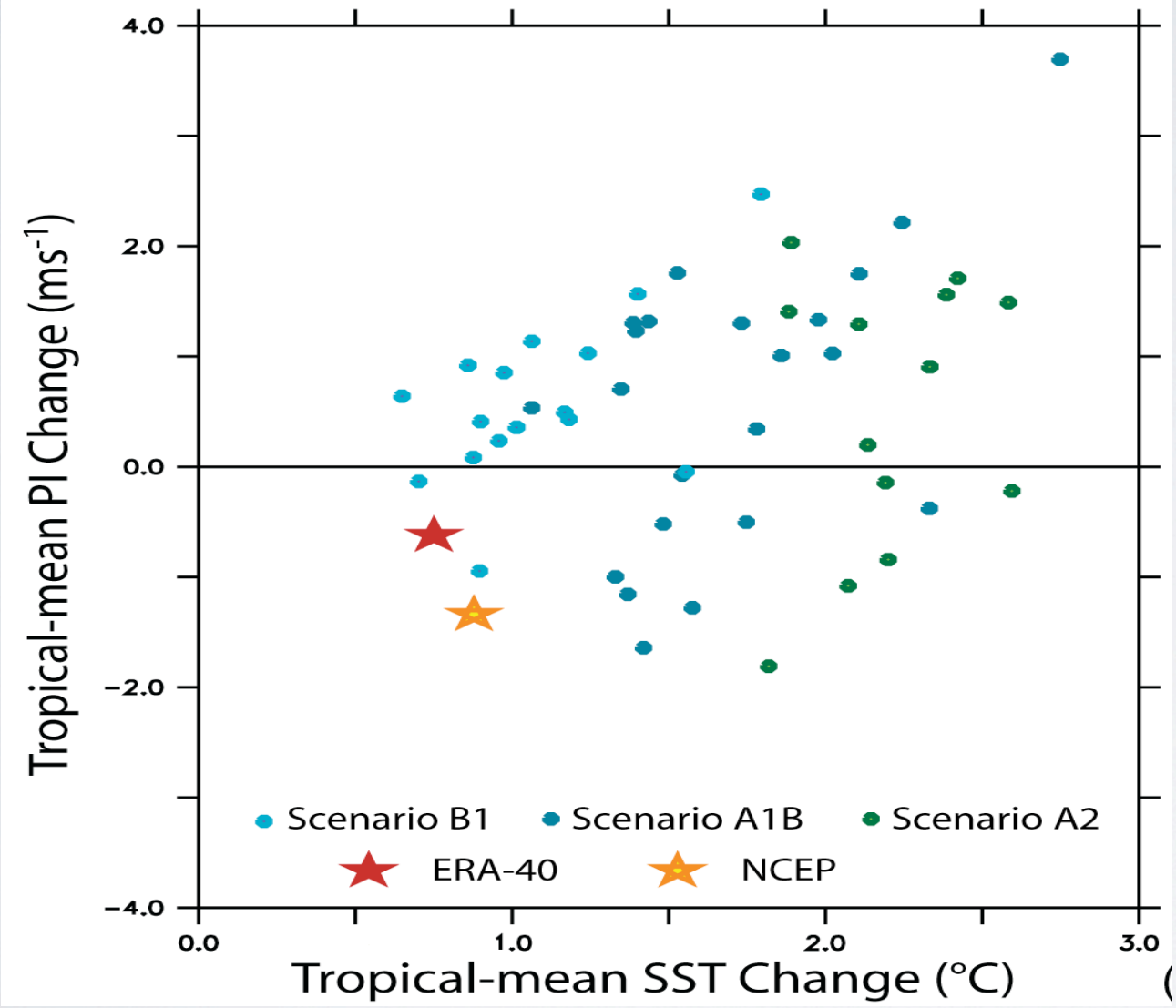
*global-mean PI changes still need to be explained.

PI Projection SST Projection



Vecchi and Soden (2007, Nature)

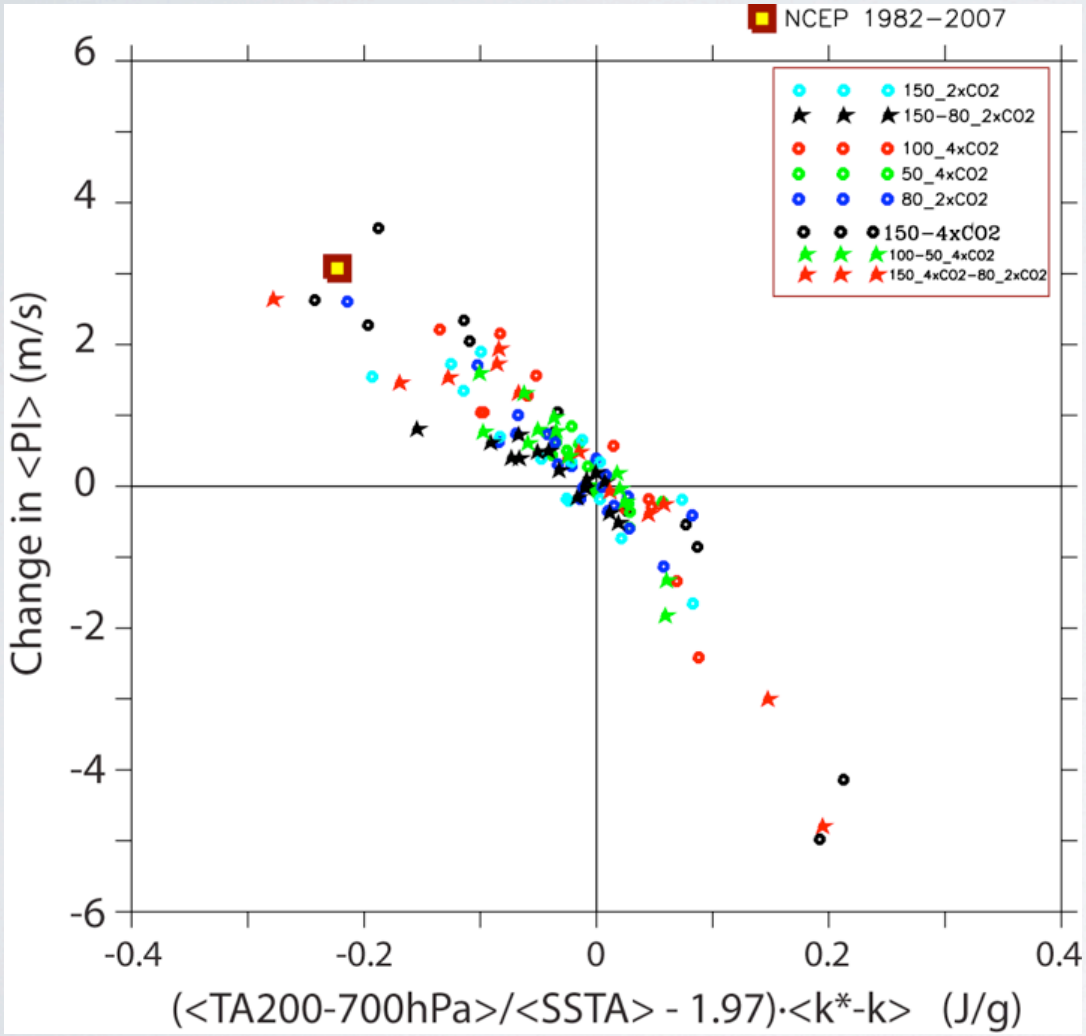
WHAT ABOUT TROPICAL-MEAN PI CHANGE?



Not well constrained by SST changes

Vecchi and Soden (2007, Nature)

Tropical-mean PI:
Surface Enthalpy Disequilibrium Sets Scale
Lapse Rate Change sets Sign



PI =<k*-k> ·(<TA>/<SST>-1.97)

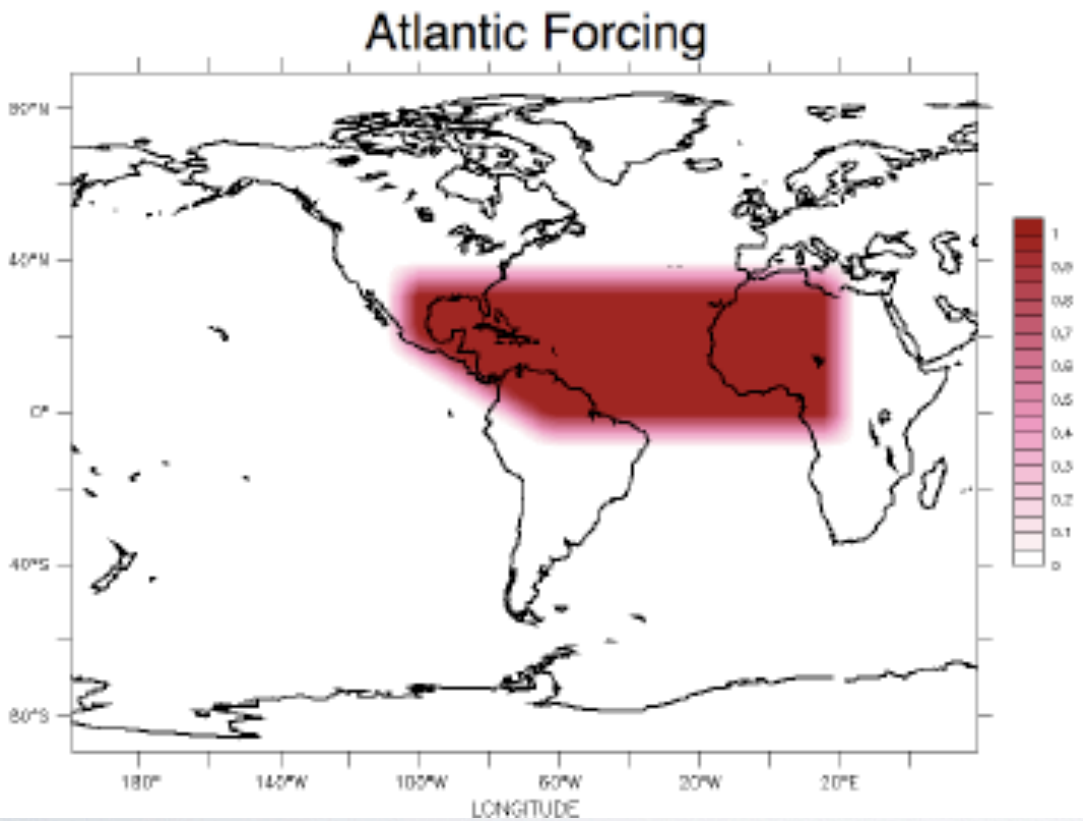
Relationship explains:
- IPCC-AR4 model decadal noise and response to 2xCO2, 4xCO2.

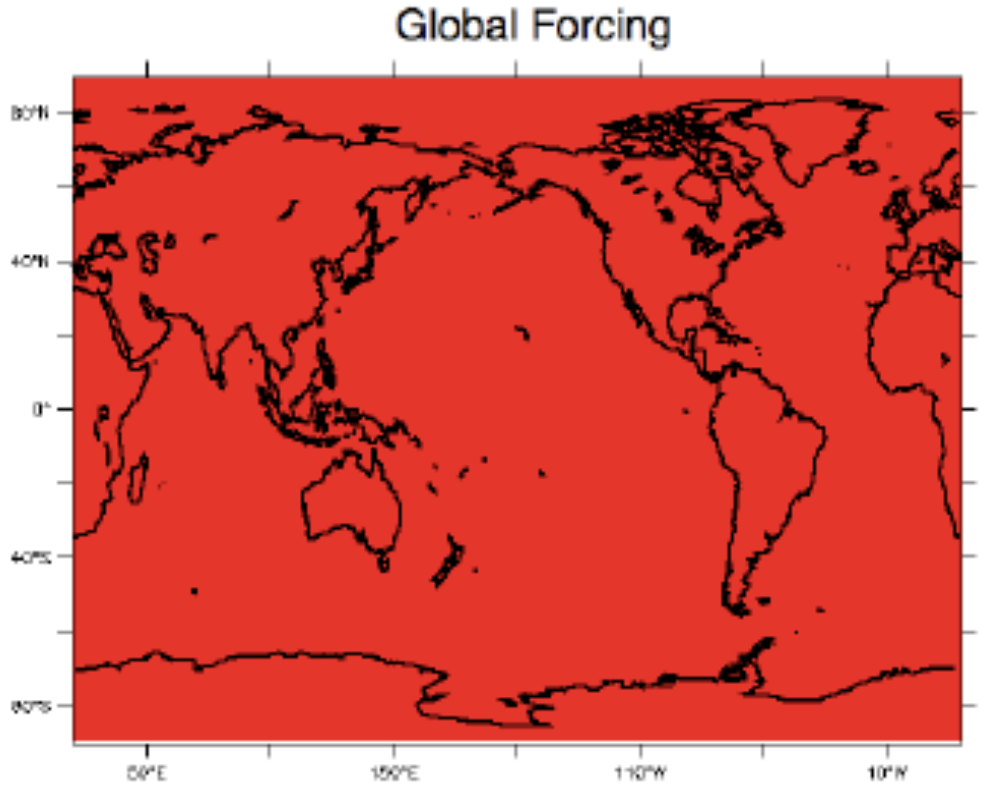
- NCEP Reanalysis trend.

Idealized Forcing Experiments

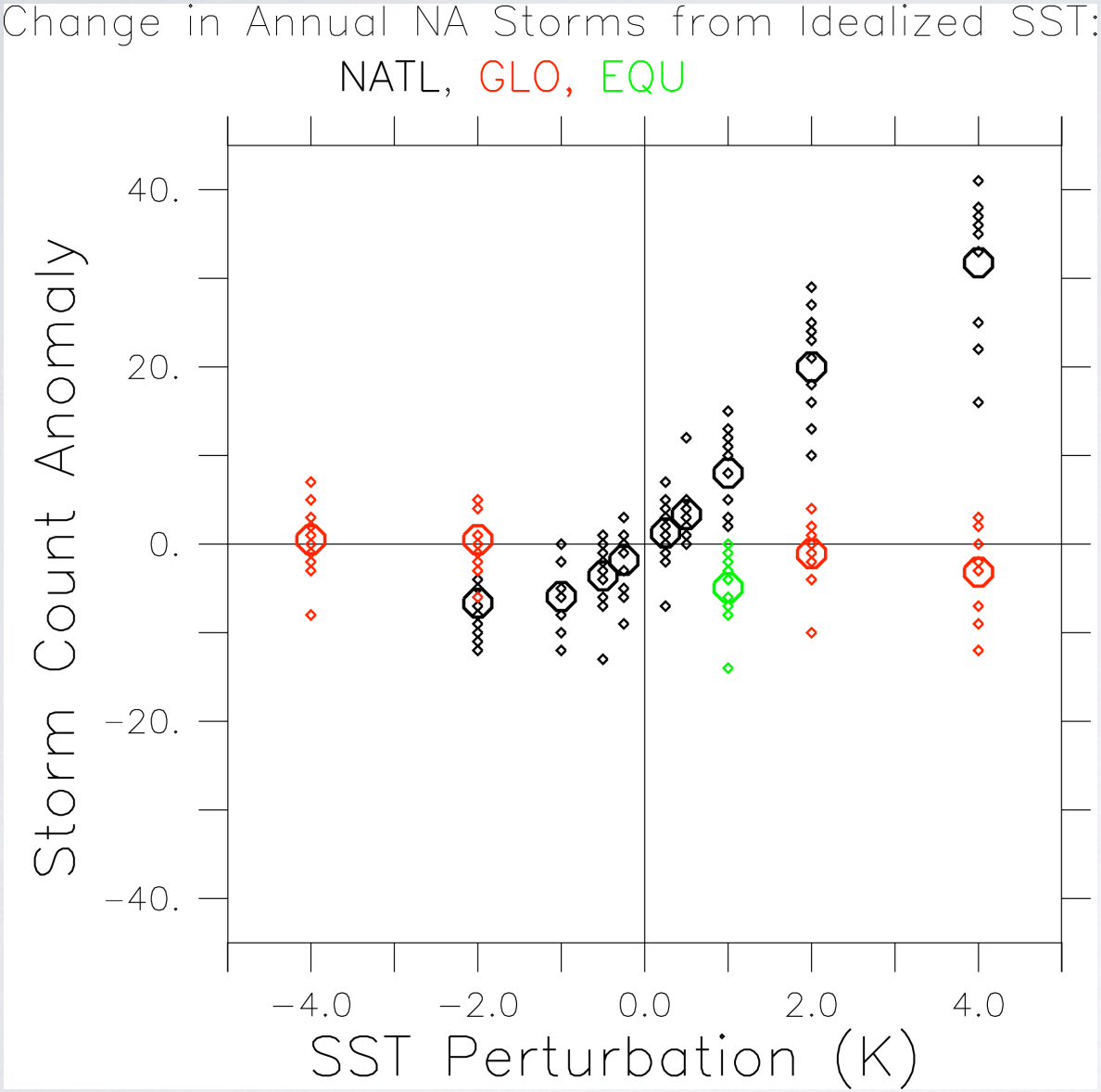
If local SST the dominant control, as opposed to relative SST:

- Similar Atlantic Response to Atlantic and Uniform F'cing
- Little Pacific Response to Atlantic compared to Uniform





North Atlantic Response to Idealized SST



Atlantic Forcing

Uniform Forcing

Near-equatorial Forcing

Similar TS frequency response to:
0.25° local warming
4° global cooling

Vecchi et al (2010, in prep.)

Principal Issues (My Biased View)

- Lack of climate-relevant theory of genesis/basin-wide frequency
- Uncertainty in past (and future) large-scale changes (e.g., SST, upper tropospheric/ tropopause layer temperature)
- Sensitivity studies with AGCMs not coordinated (meta-studies can only do so much)
- Historical cyclone database corrections adjustments need assessment, continued effort and extension needed (more, different paleo-proxies)
- Climate predictions/projections beyond frequency (landfall, extremes)
- Statistical models/downscaling techniques need to be compared and evaluated for skill/relevance to various applications (e.g., prediction, projection, proxy)
- Coupled model biases in tropical Atlantic and subsurface observations in GOM

Principal Issues (My Biased View)

- Lack of climate-relevant theory of genesis/basin-wide frequency

Elevate priority and encourage: theoretical analysis, coordinated model studies, genesis indices

- Uncertainty in past (and future) large-scale changes (e.g., SST, upper tropospheric/ tropopause layer temperature)

- Sensitivity studies with AGCMs not coordinated (meta-studies can only do so much)

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CGCM development, resolution? parameterizations? Why few subsurface GTS obs in GOM?